THE USE OF REMOTE SENSING AND ANCILLARY DATA IN GIS TO ASSESS GROUNDWATER POTENTIAL OF THE MATAYOS – FUNYULA AREA, BUSIA DISTRICT, KENYA

By

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DECLARATION

I, Bernard K. Ngoruse, hereby declare that this is my original work and has not been presented for a degree at any other University. All sources of information have been specifically acknowledged by means of references.

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Bernard K. Ngoruse

This dissertation has been submitted for the examination with our knowledge as university supervisors.

....

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.... 10/8/2009

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ABSTRACT

Matayos - Funyula area is situated in Busia district of Western province in the Republic of Kenya. The previous groundwater explorations in the area were done using seismic methods which could not appropriately explore other promising areas for groundwater exploitation.

The purpose of this study was to apply remote sensing techniques and GIS to acquire and analyse various themes of aquifer thickness, geology, land use, slope, lineament and drainage densities, and rainfall and integrating them by Index Overlay Method (IOM) to produce a groundwater potential map of the area between Matayos and Funyula in Busia district.

The study showed that the areas with the highest groundwater potential were areas that had a low elevation and gentle slope, a high lineament density. The Recent (Alluvial) Sediments had the highest potential for groundwater.

Satellite data has proven to be very useful and informative for surface and sub-surface study, as it gives preliminary and good background information on features such as lineaments and drainage density and other structures important to groundwater storage.

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CHAPTER 1 INTRODUCTION AND GEOGRAPHICAL ASPECTS

1.0 Introduction

Remote sensing with its advantages of spatial, spectral and temporal availability of data covering large and inaccessible areas within short time has become a very handy tool in assessing, monitoring and guiding in conservation of groundwater resources. Satellite data provide quick and useful baseline information on the parameters controlling the occurrence and movement of groundwater like geology, geomorphology, soils, land use/cover, lineaments etc. However all the controlling parameters have rarely been studied together because of non-availability of data, integrating tools and modelling techniques. Hence a systematic study of these factors leads to better delineation of prospective groundwater occurrence zones in an area.

Remote sensing and GIS methods and modelling were used in the study area to assess analyse and delineate all the potential areas where groundwater can be further explored using ground methods, for example, 2-D electrical imaging, seismic reflection and others.

1.1 Description of the area

1.1.1 Location

The Matayos – Funyula study area is situated in Busia district of Western province in the Republic of Kenya. It is bound by latitudes 0^0 15’ 44.3” N to 0^0 23’ 20.2” N and longitude 34^0 02^0 32.7"E , and 34^0 11’ 10.3” E respectively. Administratively it covers parts of Matayos and Funyula divisions. The area studied is between the Odiado hills and River Sio to the south east and north west respectively, and between Matayos-Bumala road and Luanda-Funyula road to the northeast and southwest respectively. It is approximately 50 km^2 measuring about 10 km (NE-SW) and 5 km (NW-SE)

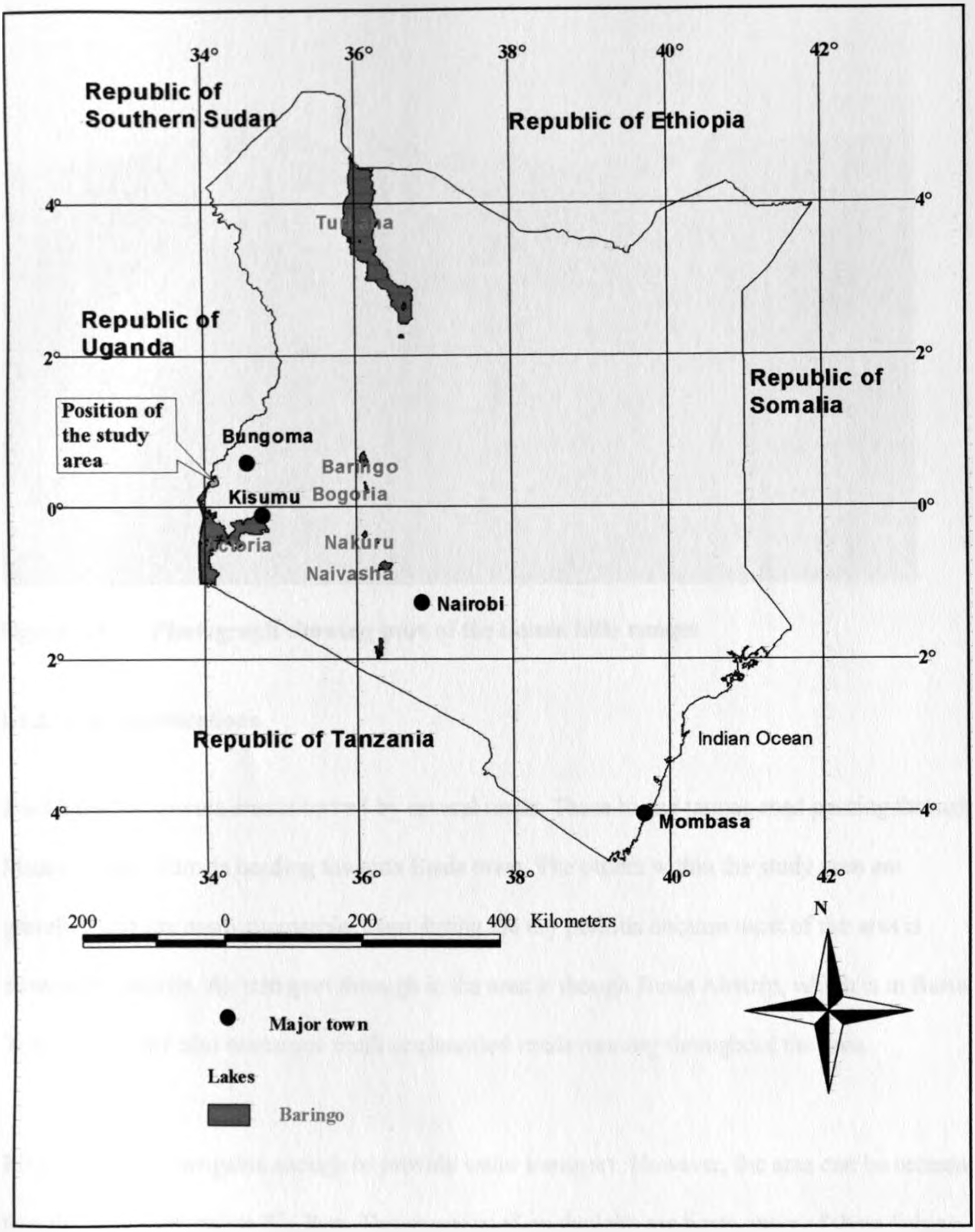


Figure 1.1 Administrative Map of Kenya showing the position of the study area

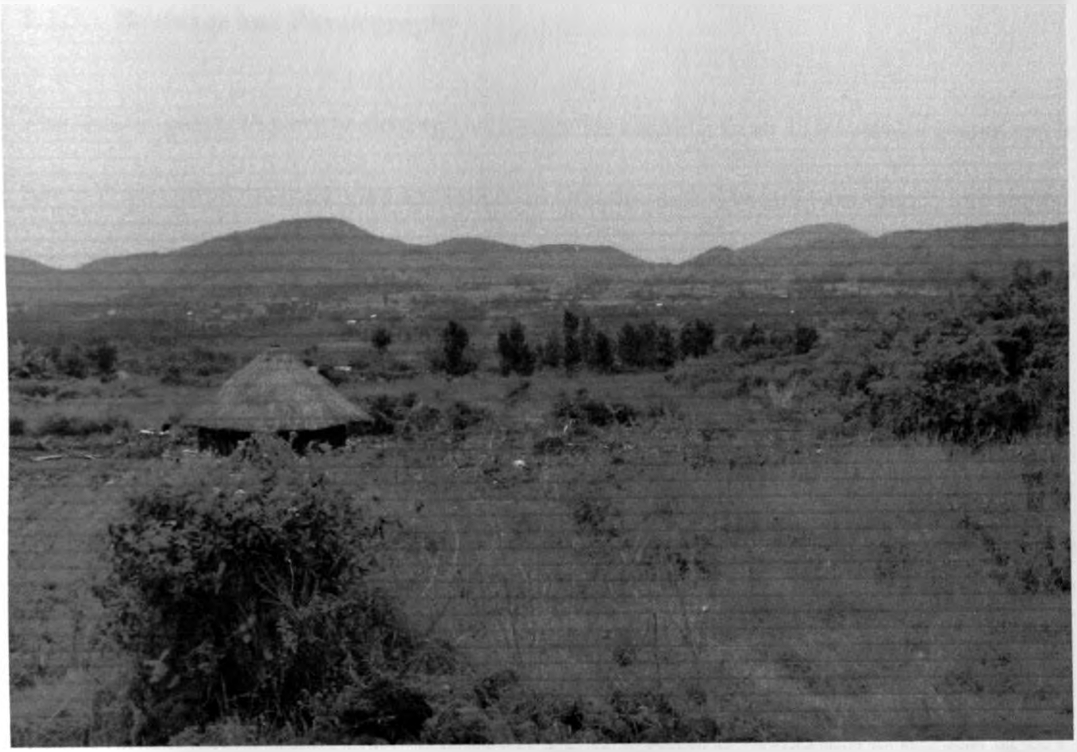


Figure 1.2 Photograph showing part of the Samia hills ranges

1.1.2. Communications

The Matayos-Funyula area is served by several roads. There is one tarmac road passing through Matayos from Bumala heading towards Busia town. The others within the study area are gravelled and are easily motorable, even during the dry periods because most of the area is covered by laterite. Air transport through in the area is though Busia Airstrip, which is in Busia Town. There are also numerous small unclassified roads running throughout the area.

River Sio is not navigable enough to provide water transport. However, the area can be accessed though Lake Victoria via Sio Port. The means used on the lake are boats, most of them fishing vessels.

1.1.3 Drainage and Physiography

The area is gently to steeply sloping, with altitudes ranging from 1160 metres above sea level on River Sio to 1568 metres above sea levels on Odiado hills. The hills are ranges and their orientation is from north east to south west, and these control the drainage of the general area. The valleys are mainly u-shaped from where semi-permanent springs flow.

The drainage system, which develops in an area, is dependent on the slope, the nature and attitude of bedrock and on the regional fracture pattern (Travaglia, 2003). Drainage reflects to varying degrees lithology and structure of a given area and can be of great value for groundwater resources evaluation. Drainage is studied according to its pattern type and its texture (or density of dissection). Whilst the first parameter is associated to the nature and structure of substratum, the second is related to rock/soil permeability (and, thus, also the rock type). Actually the less the rock is permeable, the less infiltration of rainfall, which conversely tends to be concentrated in surface runoff. This gives origin to a well-developed drainage system. On the other hand, in karst regions where the underground circulation of water is much more developed than the surficial one, drainage is less developed or missing altogether.

The drainage is dendritic at the sources between the hills, and tributaries to river Sio become sub-parallel in the middle and lower course. These are in tree-like formation and join at acute angle, a common pattern in homogeneous rocks such as volcanic tuffs. The streams move to the north, south and westwards following the hill ranges structure in straight patterns along the hill ranges and between the breaks in the hills. This is indicative of a fault or fracture zones. These streams then join the main River Sio at an angle. The river, cutting through its alluvial deposits occupies a mature wide valley and is bordered by marshes or flats over the greater part of its depth.

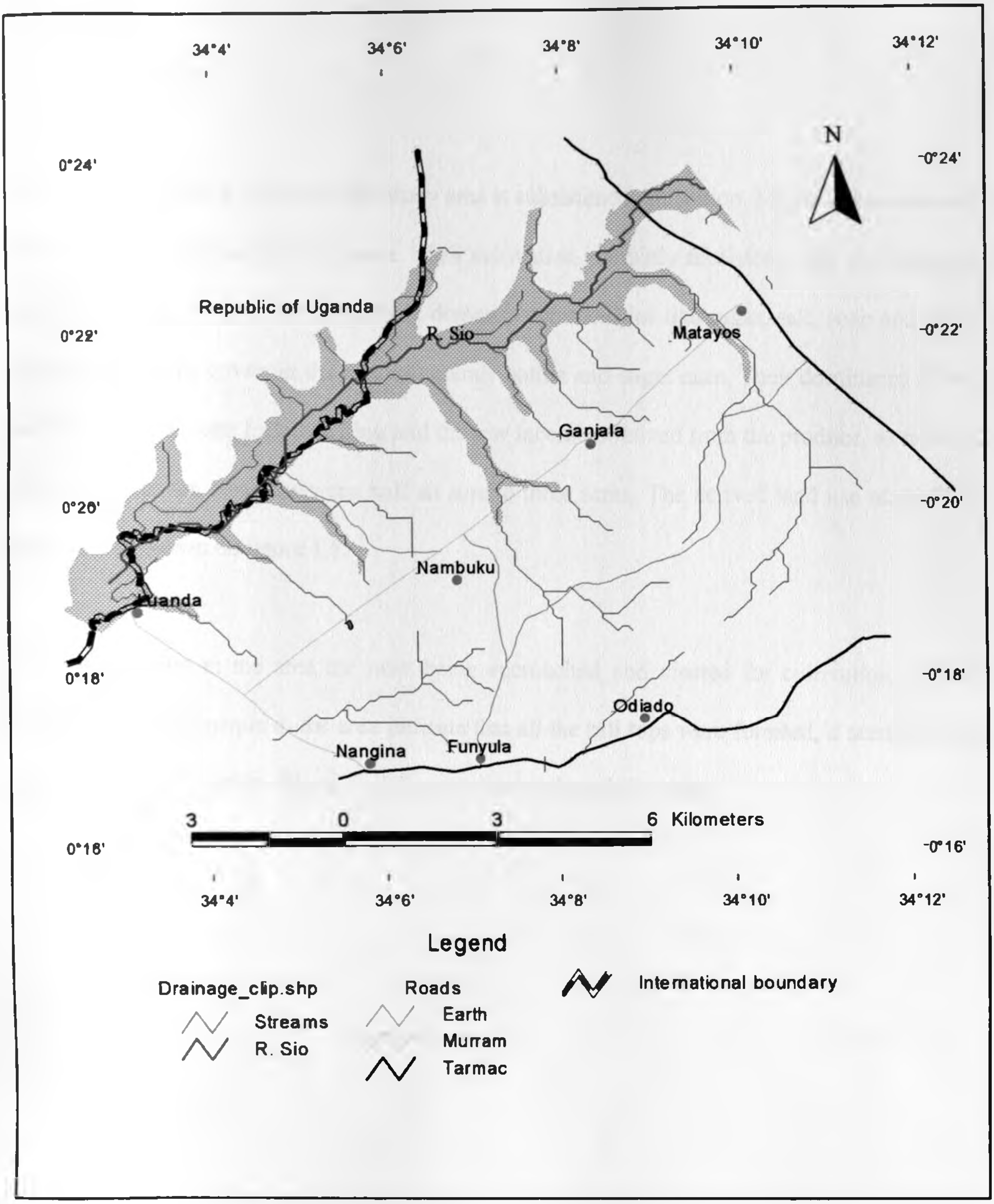


Figure 1.3: Drainage map of the study area showing features. The drainage of river Sio is structurally controlled. Tributaries are sub-parallel at middle and lower course.

1.1.4. Land cover

The main agricultural activity in the study area is subsistence cultivation. Maize and cassava are the main food crops grown in the area. Their cultivation is mainly subsistence and the surplus is sold in the local markets for other basic domestic commodities like sugar, salt, soap and many others. Cash crops grown in the area are mainly cotton and sugar cane. Their dominance is low due to lack of markets for processing and the low income obtained from the produce, as most of the land pieces are small, between half an acre to three acres. The derived land use map of the study area is shown on figure 1.5.

Most of the hills in the area are now being encroached and cleared for cultivation. Verbal accounts from the people in the area indicate that all the hill tops were forested, a scenario that has changed considerably. There is no forest cover on these hills today.

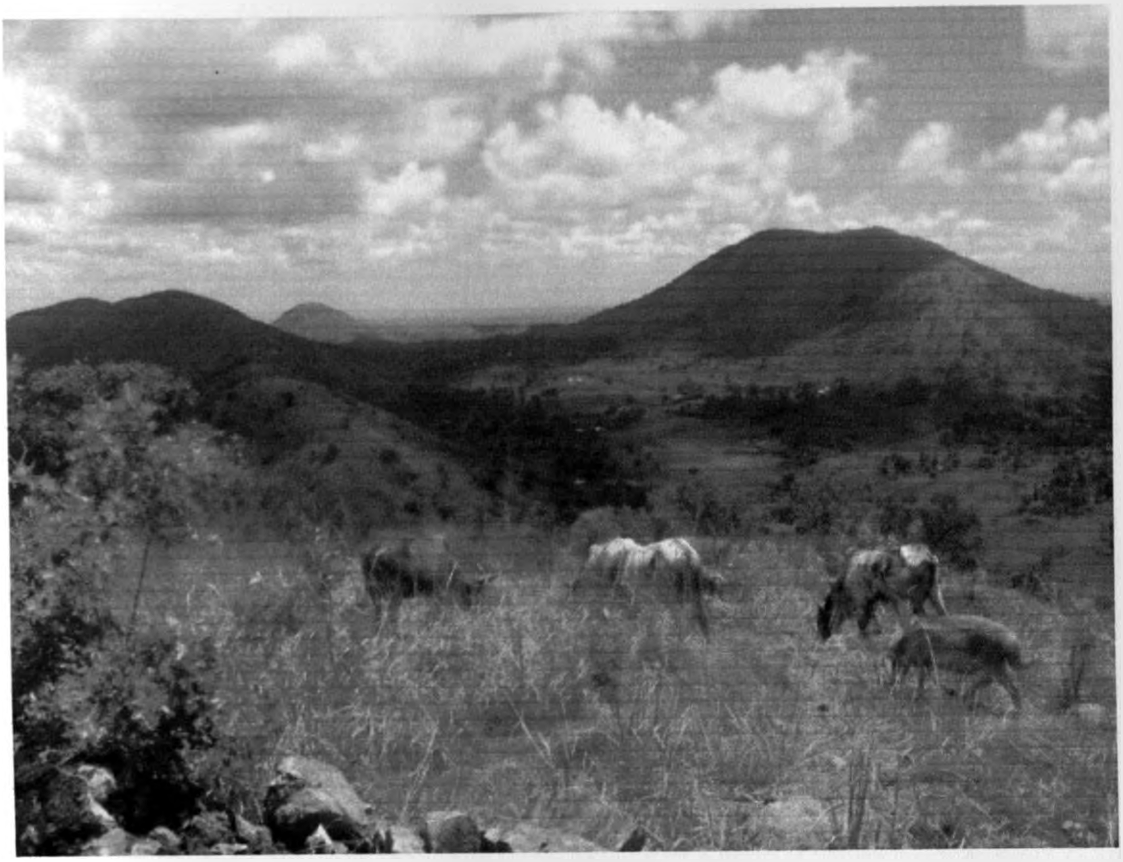


Figure 1.4: Photograph showing land use in the study area. The hill tops have grass and shrubs, and agricultural activities are carried out in the valleys.

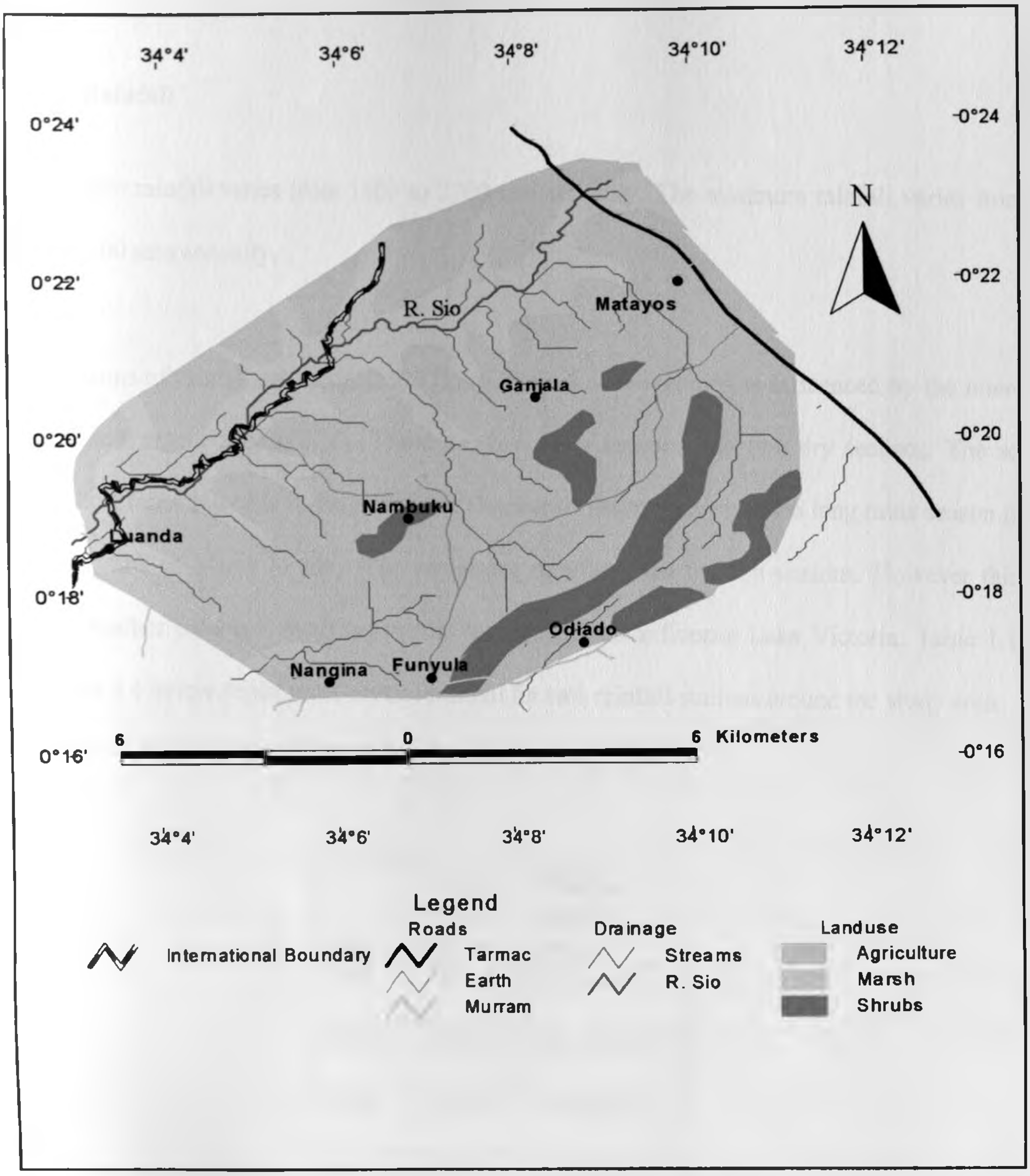


Figure 1.5: Land use map of the study area

1.1.5. Rainfall

The highest rainfall varies from 1100 to 2700 mm annually. The minimum rainfall varies from 600 to 1100 mm annually.

Four seasons of rainfall are recognized. This is typical of the tropics as influenced by the inter-tropical convergent zone (ITCZ). There are two rainy seasons and two dry seasons. The so called short rains season is in the months of October to December while the long rains season is in the months of March to May. The remaining months form the dry seasons. However this regular weather pattern is modified by the local relief and influence Lake Victoria. Table 1.1 and figure 1.6 below depict mean annual rainfall for two rainfall stations around the study area.

Table 1.1.: Annual rainfall of two stations around the study area

Year	Alupe rainfall station	Nangina rainfall station
1997	2022.5	No record
1998	1691.4	No record
1999	2333.8	No record
2000	1510.9	No record
2001	1507.9	No record
2002	1813.8	No record
2003	1762.5	1090.6
2004	1801.7	1108.8
2005	1454.9	1363.6

(Source: Ministry of Water & Irrigation, Busia District Office)

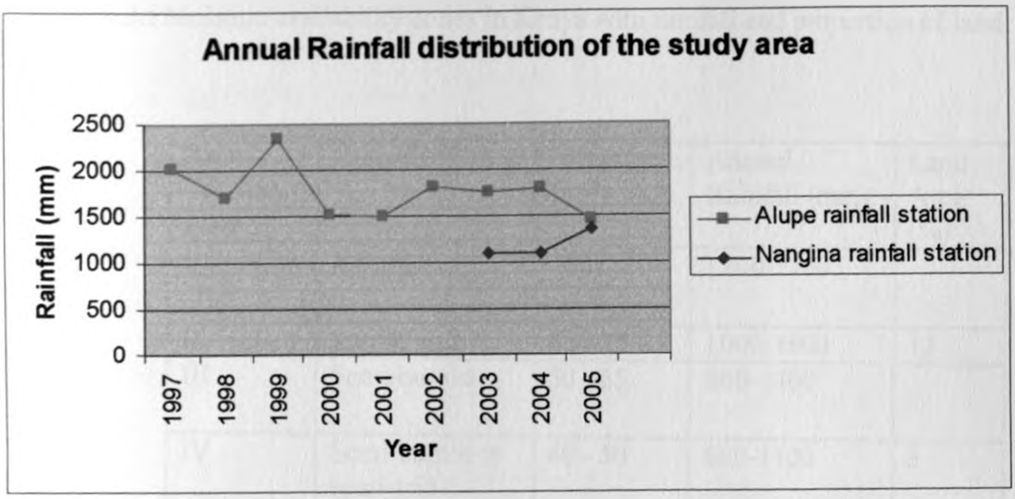


Figure 1.6: Graph showing annual rainfall distribution within the study area.

1.2 Climate and Agro-Ecological Zones

Climate, vegetation and land use potential have been used to assess land suitability for different uses. The major elements of climate that affect herbage growth are the intensity and duration of rainfall, the relationship between annual rainfall and potential evapo-transpiration, and the year-to-year variation in rainfall. Kenya is divided into seven agro-climatic zones using a moisture index based on annual rainfall expressed as a percentage of potential evaporation. Areas with an index greater than 50% have high potential for cropping, and are designated zones I, II, and III. These zones account for 12% of Kenya's land area. The semi-humid to arid regions (zones IV, V, VI, and VII) have indices of less than 50% and a mean annual rainfall of less than 1100 mm. These zones are generally referred to as the Kenyan rangelands and account for 88% of the land area.

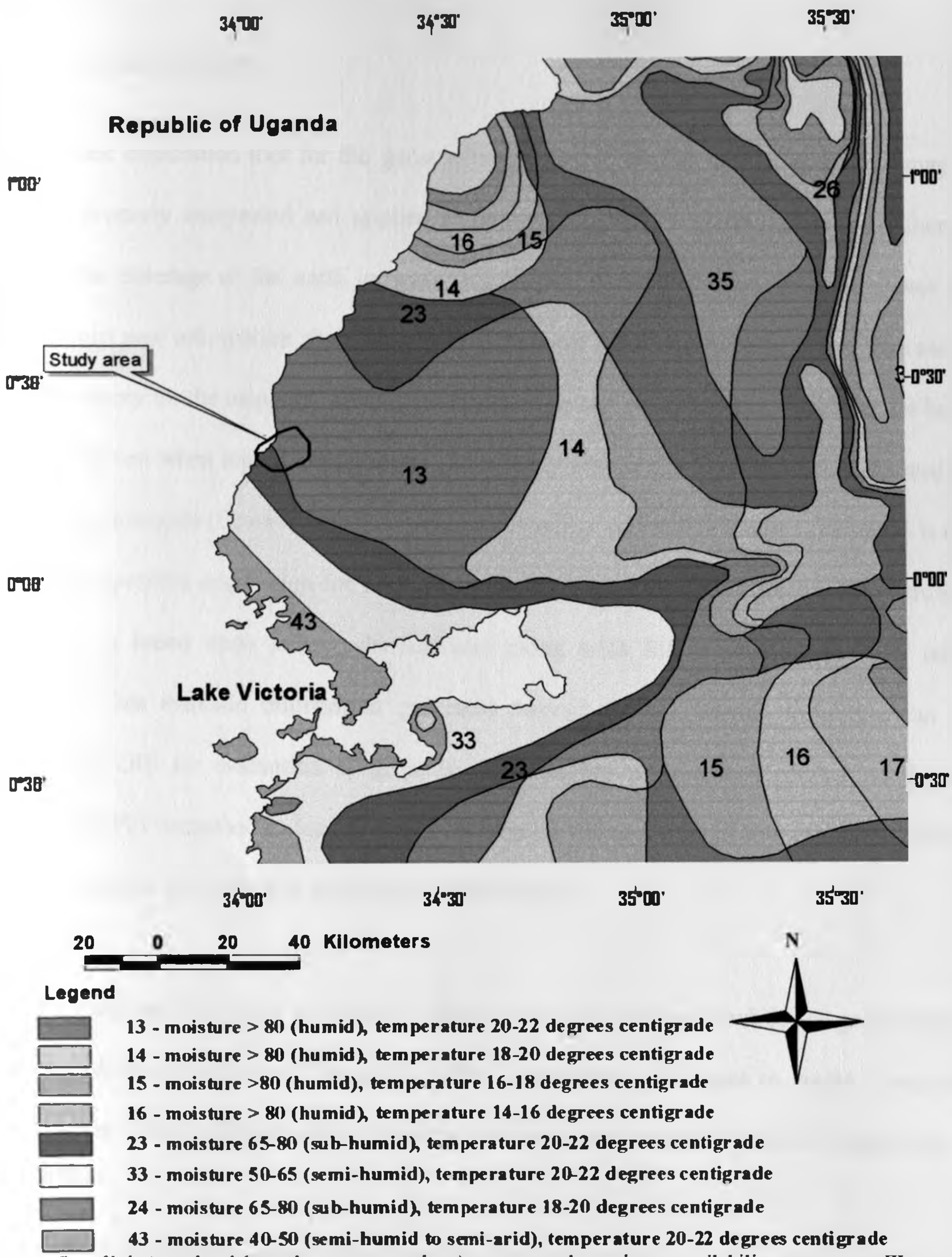
Table 1.2.: Moisture availability zones in Kenya with rainfall and proportion of land

Agro - Climatic Zone	Classification	Moisture Index (%)	Annual Rainfall (mm)	Land Area (%)
I	Humid	>80	1100-2700	
II	Sub-humid	65 - 80	1000-1600	12
III	Semi-humid	50 - 65	800-1400	
IV	Semi-humid to semi-arid	40 - 50	600-1100	5
V	Semi-arid	25 - 40	450-900	15
VI	Arid	15 - 25	300-550	22
VII	Very arid	<15	150-350	46

(From Kenya: Country Pasture/Forage Resource Profiles)

The seven agro-climatic zones are each sub-divided according to mean annual temperature to identify areas suitable for growing each of Kenya's major food and cash crops. Most of the high potential land areas are located above 1200 m altitude and have mean annual temperatures of below 18° C, while 90% of the semi-arid and arid zones lies below 1260 m and has mean annual temperatures ranging from 22° C to 40° C.

The general climate of the study area is mainly tropical humid characterized by day temperatures varying between 16° C in the highland areas of Cherangani and Mt. Elgon to 28° C in the lower semi-arid areas. The mean annual night temperatures vary between 4° C in the highland areas to 16° C in the semi-arid areas. The area falls under the Climatic Zone II which is sub humid with temperatures ranging from 20° to 22° C.



The first digit (translated from the roman numbers) represents the moisture availability zones, e.g., III becomes 3. The second digit represents the temperature zones. Therefore, 31 in the coverage represent Zone III-1. Temperature in degrees centigrade, moisture index in %

Figure 1.7: : Extract of climate map of Kenya showing the climatic zone of the study area
(Adapted from www.ilri.org/gis/search1m.asp by International Livestock Research Institute)

1.3. Literature Review

A significant exploration tool for the geoscientist is remote sensing from space. The imagery obtained, properly interpreted and applied to global research for groundwater and minerals, provides the coverage of the earth in ways which were heretofore impossible and gives the explorationist new information about the land and water of the earth (Reeves, 1968). The use of satellite imagery for the mapping of the geological terrain can provide maps, which can be basic documents (even when topographical maps of the study area are available) for further detailed research by geologists (Gossens, 1991). The main advantage of satellite images over maps is the timely and repetitive acquisition for determining landscape changes and trends. Groundwater exploration is based upon terrain characteristic along with lithology, land use and other parameters. This thematic information generated through remote sensing technique can be integrated in GIS for evaluation of groundwater resources as has been carried out in the Rawasen and Pili watershed in lesser Himalayas with the Ganga River as the western boundary and it lies between Haridwar and Kotdwara towns in India.

Remote sensing has also been successfully used in the Arab Syrian Republic for groundwater assessment in the Nijran area (Travaglia, 1998). Lineaments were used to create a map of potential areas using satellite images of the area. One well was successfully drilled in the area.

Apart from direct benefits, space technology has demonstrated its usefulness in understanding the factors responsible for maintaining the hydrological cycle, mainly the vegetative cover, surface water bodies, lithotypes and landform. The occurrence and movement of groundwater is controlled by lithology, soils, vegetative cover and land use; most of this information is obtainable from satellite imagery. One has to interpret first these controlling features and then proceed for delineation of groundwater potential zones. This type of integrated approach was adopted in targeting groundwater potential zones in major hard rock areas in Southern and Central India (Rao, 1982).

The use of remote sensing and GIS in groundwater studies has also been successfully applied in Burdur area in Turkey (Sener, et al, 2005) where groundwater potential zones were demarcated and investigated in detail.

The use of models for groundwater investigation has also been used to analyse the pollution potential of groundwater in the Mombasa area off the Kenyan coast (Munga, et al, 2004). The study delineated groundwater zones which were highly vulnerable to contamination. The same model, modified, can also be used to estimate the water resources potential of an area.

No studies have been conducted in the study area using remote sensing for groundwater assessment.

1.4 Statement of the problem

Groundwater exploration, especially in the lower parts of the study area has not been executed with much success. A good number of the drilled boreholes were recorded to be dry, or low yielding. Seismic methods were used for exploration. This could possibly have led to other significant areas to be omitted in exploration, as the explored sites were based on the investigator's preference. This study therefore embarks to apply remote sensing methods using satellite imagery as a reconnaissance exploration tool which can then be followed up using direct exploration methods, for example 2D electrical imaging.

1.5. Objectives of the research work

- To collect the ancillary data and to analyse the remote sensing data for getting information that is related to groundwater occurrence and create thematic maps.
- To apply the integration of remote sensing data and GIS for forecasting of groundwater potential zones in the study area between Matayos and Funyula.

CHAPTER 2 : GEOLOGY AND HYDROGEOLOGY

2.0. Geology

The geology of the study area is mainly composed of the Nyanzian System and the Kavirondian System. The Banded Iron Formation within the Nyanzian system defines the Samia hills ranges.

2.1. Nyanzian System

2.1.1 Nyanzian volcanics

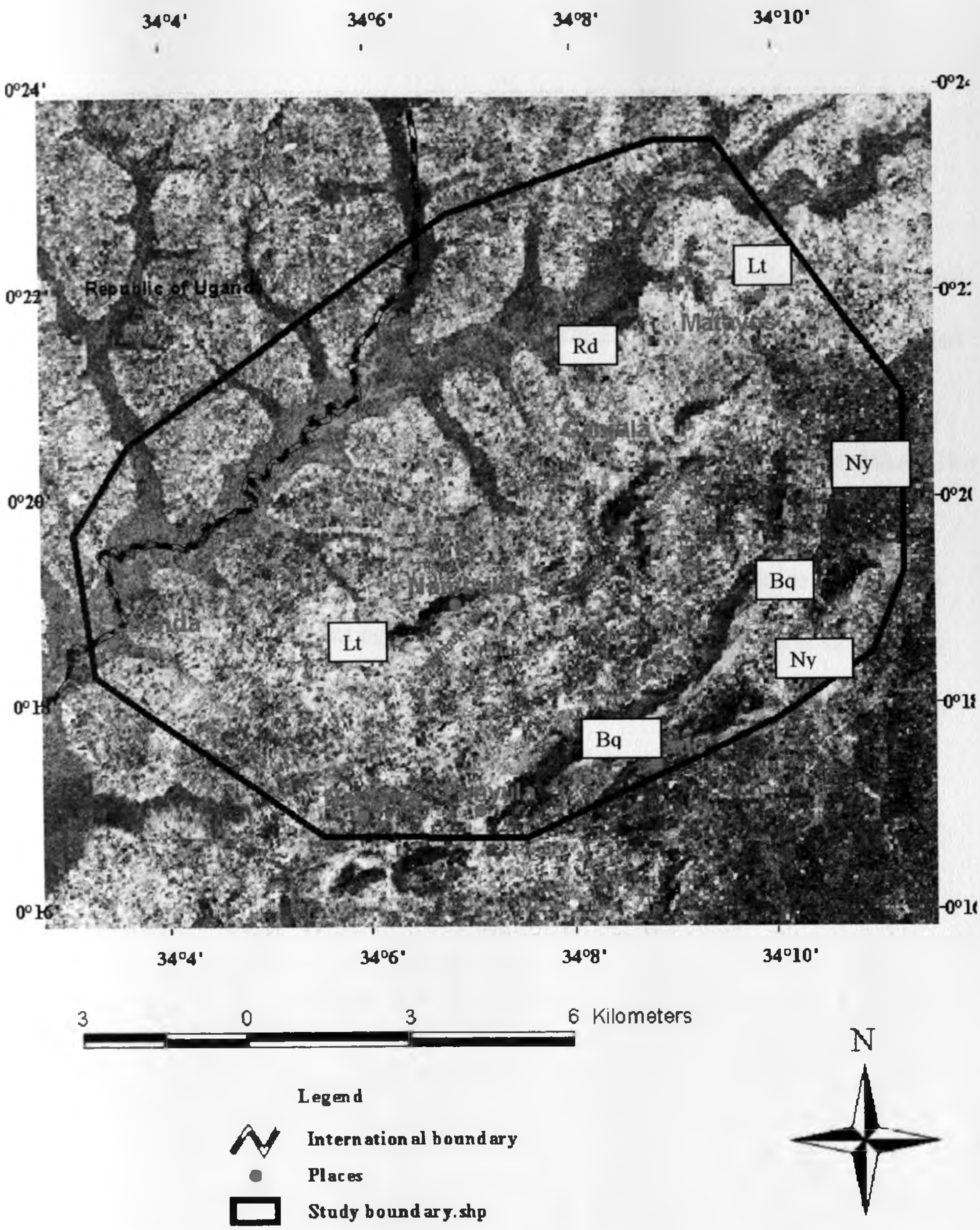
The Nyanzian, about 7500 m thick, consists of a basal mafic volcanic group composed mostly of pillow lavas with local banded iron formation, followed by an intermediate to acid volcanic group of ryolites, subacid lavas with intercalated tuffs and agglomerates (Schülter, 1997). These pass upward into greywackes with andesitic tuffs near the top. A slaty and andesitic group overlies the whole succession. The Nyanzian has simple folds and shear belts with local isoclinal folding and thrusts. The tuffaceous silty and ferruginous slates occur at the base of the slaty and andesitic unit while the banded iron formation occurs near the top.

In the study area the Nyanzian system is represented by andesites. In hand specimen these are medium green-grey and often carry feldspar phenocrysts. Less commonly mafic minerals are also visible to the naked eye.

Figure 2.1 : Photograph showing andesite outcrop in the study area in Odiado

2.1.2 Banded Quartzites

The banded quartzites are composed of recrystallised haematite and magnetite (Ingana, 1993). There is a general development of granules, mainly of iron silicate. They are ovoid or bean shaped and range from a fraction of a millimetre to a few millimetres. They do not display concentric or radiating structures. The deposition of iron takes place as a ferric oxide, ferrous carbonate, ferrous silicate or pyrite depending on the pH and redox potential of the environment. The presence of 'banding' shows that the rock was deposited in a relatively quiet and deep water environment.



Bq	Banded quartzites
Rd	Recent deposits
Ny	Nyanzian Andesites
Lt	Laterites

Figure 2.2: Satellite image of band combination 7-5-2 showing the geology of the study area

2.1.3 Laterite

Laterite is a surface formation in hot and wet tropical areas which is enriched in iron and aluminium and develops by intensive and long lasting weathering of the underlying parent rock. Nearly all kinds of rocks can be deeply decomposed by the action of high rainfall and elevated temperatures. The percolating rain water causes dissolution of primary rock minerals and decrease of easily soluble elements as sodium, potassium, calcium, magnesium and silicon. This gives rise to a residual concentration of more insoluble elements predominantly iron and aluminium. Laterites consist mainly of the minerals kaolinite, goethite, hematite and gibbsite which form in the course of weathering. Moreover, many laterites contain quartz as relatively stable relic mineral from the parent rock. The iron oxides goethite and hematite cause the red-brown colour of laterites. This formation covers most of the area under study.

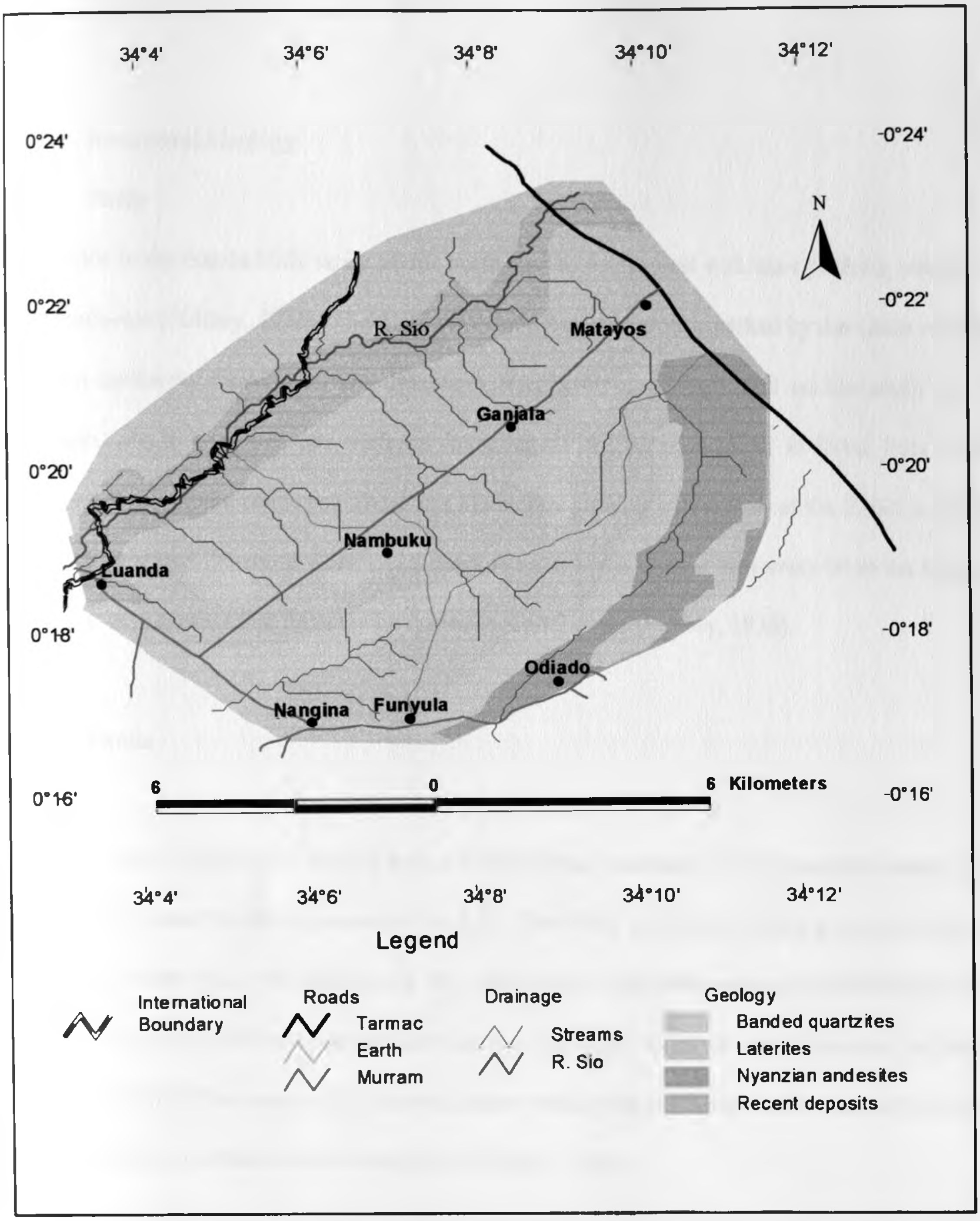


Figure 2.3: Geological map of the study area

2.2. Structural Geology

2.2.1 Folds

The folds in the Samia Hills strike about north-east to south-west with axes pitching steeply to the south-east (Pulfrey, 1936). There are two complementary folds marked by the chain of hills. On the northwest, there is an anticline with steeply dipping limbs, and on the south east a syncline, which, however, has suffered inversion so that it is isoclinal in form, both limbs steeping deeply to the southeast. There is a distinctive packing of the folds at the thrust points in the north-east and the south-west, and a marked gape in the central area away from the turning points. It is suggested that this may be due to torsional stress (Pulfrey, 1936).

2.2.2. Faults

In Samia hills, many faults can be traced breaking the continuity of the quartzite bands and giving rise to bands in the alignment of the hills. The effect of faulting can be seen from almost any point on the hills. The majority of the faults strike west-north-west and north-north-west, though occasional north-east fractures are known. The faults cannot be traced beyond the limits of the steep hills. The nature of the faulting is not readily determinable, but it is considered that they are tension, not thrust faults according to Pulfrey (1936).

2.3 Seismic methods in groundwater investigations

Seismic methods are the most commonly conducted geophysical surveys for engineering and groundwater investigations. Seismic refraction provides engineers and geologists with the most basic of geologic data via simple procedures with common equipment.

Any mechanical vibration is initiated by a source and travels to the location where the vibration is noted. These vibrations are seismic waves. The vibration is merely a change in the stress state due to a disturbance. The vibration emanates in all directions that support displacement. The vibration readily passes from one medium to another and from solids to liquids or gasses and in reverse. A vacuum cannot support mechanical vibratory waves, while electromagnetic waves can be transmitted through a vacuum. The direction of travel is called the ray, ray vector, or ray path. Since a source produces motion in all directions the locus of first disturbances will form a spherical shell or wave front in a uniform material. There are two major classes of seismic waves: body waves, which pass through the volume of a material; and, surface waves, that exist only near a boundary.

Body waves are the fastest travelling of all seismic waves and are called compressional or pressure or primary wave (P-wave). The particle motion of P-waves is extension (dilation) and compression along the propagating direction. P-waves travel through all media that support seismic waves; air waves or noise in gasses, including the atmosphere. Compressional waves in fluids, e.g., water and air, are commonly referred to as acoustic waves.

The second wave type is the secondary or transverse or shear wave (S-wave). S-waves travel slightly slower than P-waves in solids. S-waves have particle motion perpendicular to the propagating direction, like the obvious movement of a rope as a displacement speeds along its length. These transverse waves can only transit material that has shear strength. S-waves therefore do not exist in liquids and gasses, as these media have no shear strength.

S-waves may be produced by a traction source or by conversion of P-waves at boundaries. The dominant particle displacement is vertical for SV-waves travelling in a horizontal plane. Dominant particle displacements are horizontal for SH-waves travelling in the vertical plane. SH-waves are often generated for S-wave refraction evaluations of engineering sites.

The use of seismic waves was the main method of groundwater exploration in the study area done by the then Kefinco. The results of the seismic profiles done are shown in appendix 1

2.4 Hydrogeology

Fractured rock aquifers are comprised of a network of fractures that cut through a rock matrix. Characterisation of fractured rock aquifers thus requires information on the nature of both the fractures and the rock matrix. Fractures can be characterised in terms of their dimensions (aperture, length, width), their location (orientation, spacing, etc) and the nature of the fracture walls (e.g., surface roughness). The rock matrix is characterised by its pore size distribution, often expressed in terms of porosity and hydraulic conductivity.

The crystalline rocks are characterised by very low primary porosity and permeability, although this can be significantly increased by weathering and fracturing. As such, the climate, topography and rock structure are often more important in accounting for differences in well yield than the rock type. The weathered layer, in particular, can be an important source of groundwater, and thick, really extensive weathered layers can form reliable aquifers. While in arid and semi-arid regions the weathered layer is usually thin (< 1 m), in humid tropical regions its thickness may reach 100 m.

The parameter used to analyse the potential of the boreholes in the area is transmissivity. Transmissivity, T, is a measure of the amount of water that can be transmitted horizontally through a unit width by the fully saturated thickness of an aquifer under a hydraulic gradient equal to 1. Transmissivity is equal to the hydraulic conductivity multiplied by the saturated thickness of the aquifer and is given by:

$T = Kb$

where

K = hydraulic conductivity [LT-1]

b = saturated thickness of the aquifer [L].

Since transmissivity depends on hydraulic conductivity and saturated thickness, its value will differ at different locations within aquifers comprised of heterogeneous material, bounded by sloping confining beds, or under unconfined conditions where the saturated thickness will vary with the water table.

Sixty three percent of the boreholes in the study area have estimated yields of less than 5 cubic metres per hour. These boreholes were drilled in the period between 1989 and 1994 by Kefinco. This yield is considered low to serve the area population. The methods used to investigate for the boreholes were seismic methods, which were successful in some areas. Twenty six percent of the studied boreholes were dry.

Several other trials in the area yielded no results and from accounts of the area residents, no shallow wells have been successfully dug. The table 2.1 below shows the number and other details of the boreholes in the area.

Table 2.1: Data on boreholes in the study area

	BORE HOLE_ No. C	Lat	Long	TD_(M)	WSL _(M)	WRL_ (M)	YIELD_Q_M3	Specific Capacity (m3/h/m)	Transmissivity (m2/day)
1	0	0.310	34.113	100	0	0	0.000	0.000	0.000
2	5969	0.290	34.074	46		18	1.070	1.710	50.069
3	6164	0.309	34.105	58	49	13	1.310	0.110	3.221
4	6165	0.308	34.121	46	0	0	0.000	0.000	0.000
5	7890	0.295	34.120	55	38	13	8.000	0.283	8.286
6	8014	0.359	34.170	61	46	15	3.710	0.239	6.998
7	8338	0.298	34.067	40	0	0	0.099	0.006	0.182
8	8340	0.309	34.113	70	0	0	0.000	0.000	0.000
9	8834	0.367	34.121	52	20	14	10.290	0.630	18.446
10	8856	0.313	34.146	44	20	4	5.290	0.380	11.126
11	8859	0.312	34.121	37	33	18	2.900	0.330	9.662
12	8860	0.305	34.082	57	30	24	0.880	0.050	1.464
13	8864	0.340	34.109	37	27	13	1.580	0.130	3.806
14	8866	0.335	34.094	50	40	7	9.000	0.420	12.298
15	8869	0.304	34.090	52	32	30	1.230	0.110	3.221
16	9618	0.346	34.148	58	44	7	14.400	0.400	11.712
17	9619	0.342	34.171	52	32	11	14.400	1.070	31.330
18	10597	0.315	34.141	62	45	23	14.400	0.990	28.987

(Source: National Water Conservation & Pipeline Corporation, Western Regional Office, Kakamega, Ministry of water & Irrigation, Maji House)

Figure 2.4 below shows the location of the boreholes in the study area.

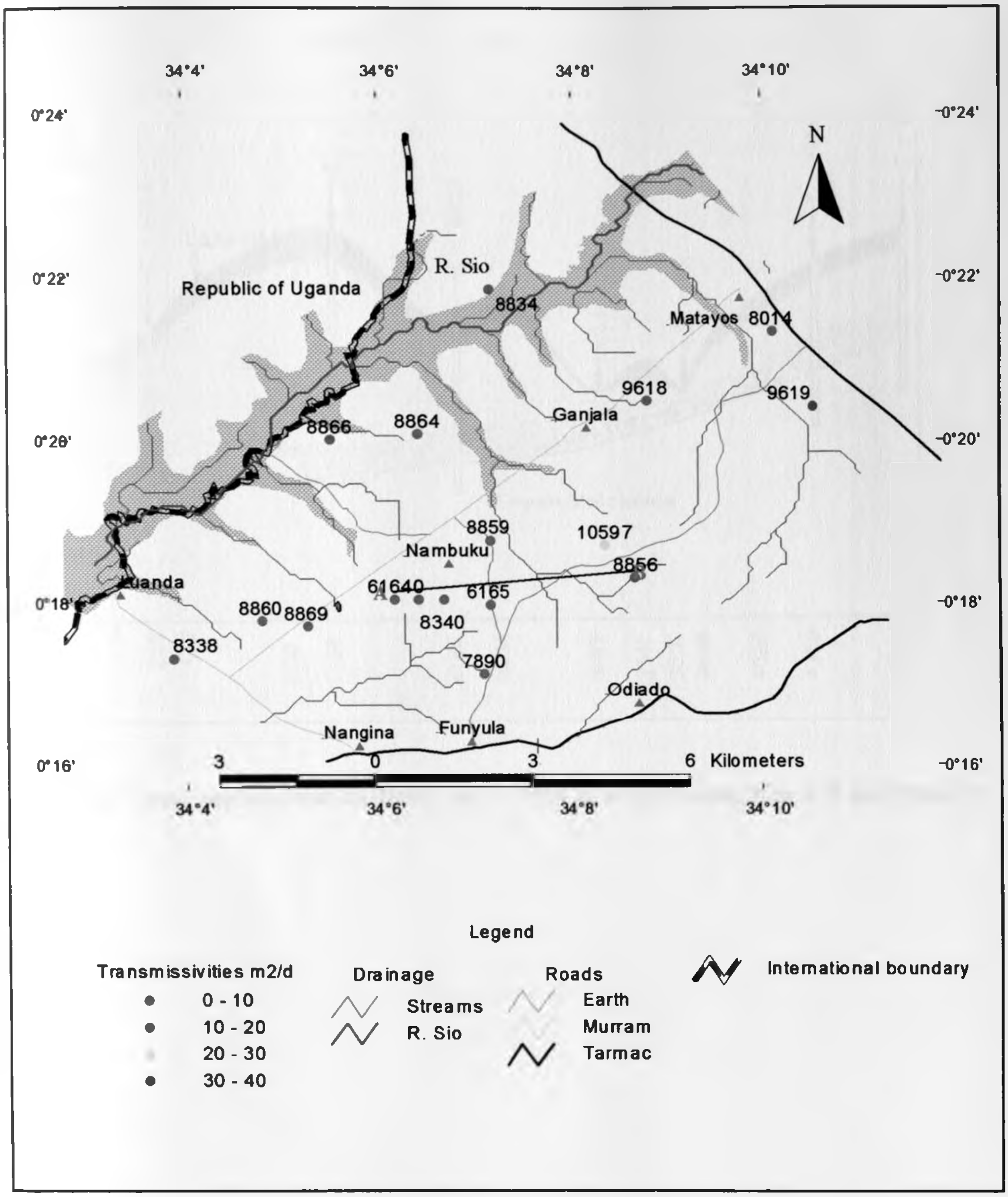


Figure 2.4: Map showing the locations and transmissivities of boreholes in the study area.

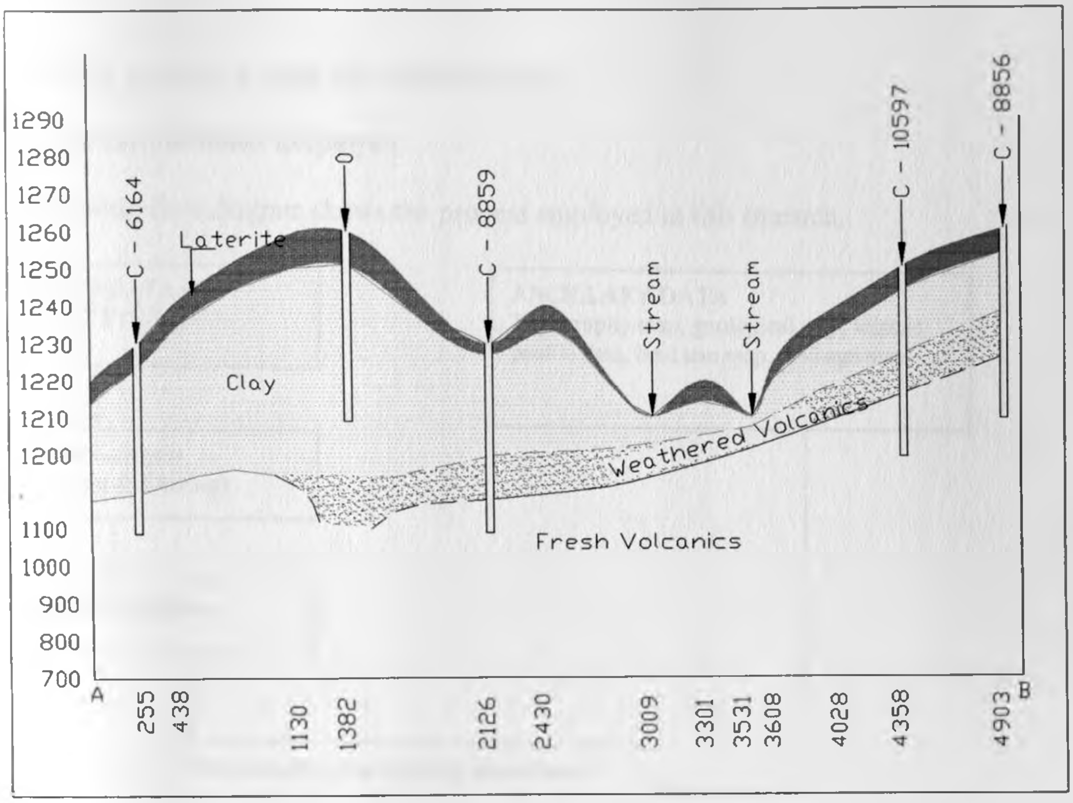


Figure 2.5: Cross section from borehole no. C- 6164 to C-8859 along line A-B on figure 2.4

CHAPTER 3 : DATA AND METHODOLOGY

3.0 Data and Methods Employed

The following flow diagram shows the process employed in this research.

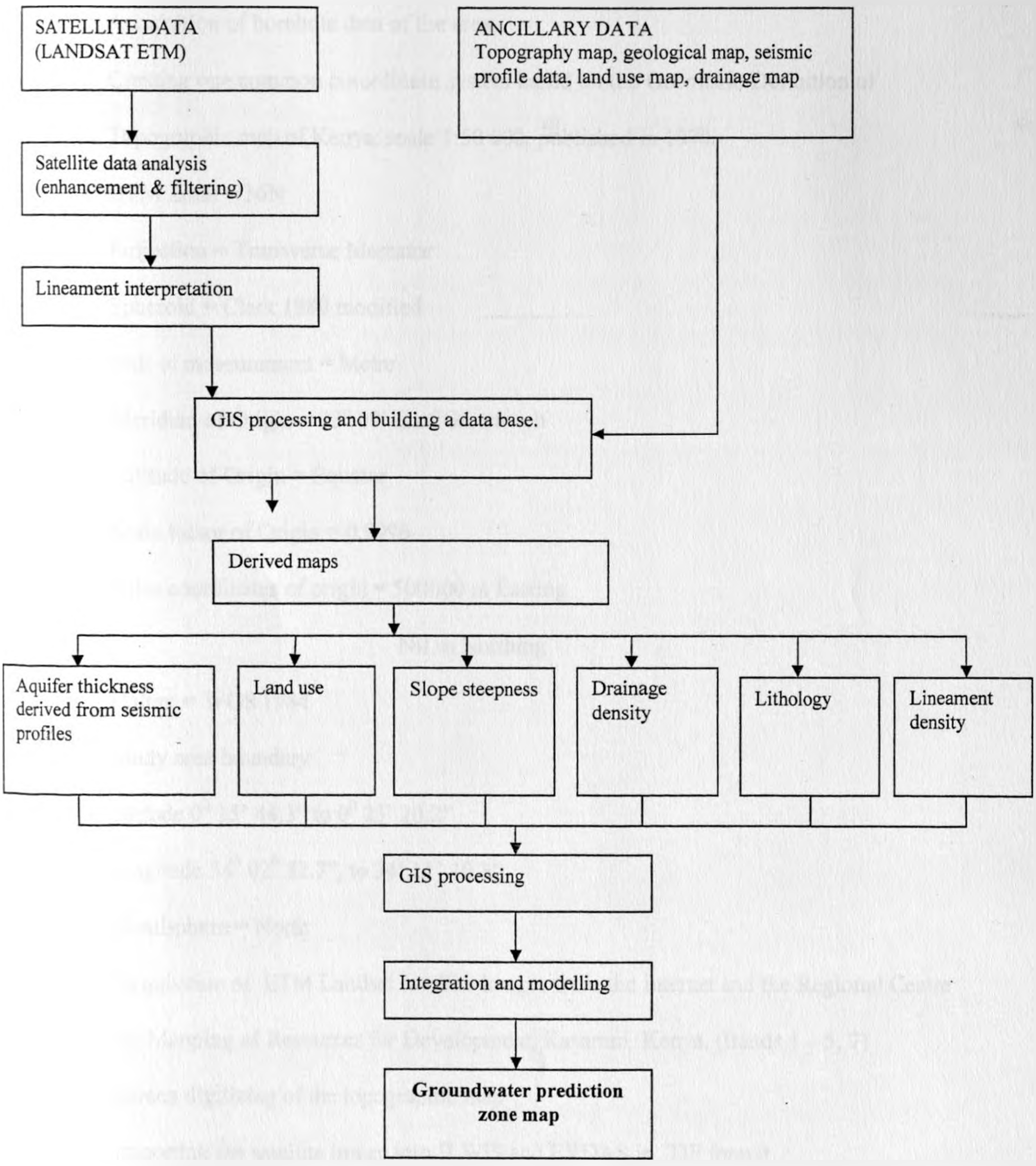


Figure 3.1: Flow diagram showing process employed

3.1 Data Collection and Processing

The following processes were applied in the research work

1. Acquisition of a scanned colour map, as Tif format, map sheet no 101/1.
2. Acquisition of borehole data of the area
3. Creating one common co-ordinate system based on the Geometric Definition of

   Topographic map of Kenya, scale 1:50 000, published in 1970.

   UTM Zone = 36N

   Projection = Transverse Mercator

   Spheroid = Clark 1880 modified

   Unit of measurement = Metre

   Meridian of Origin = 33° 00' E of Greenwich

   Latitude of Origin = Equator

   Scale factor of Origin = 0.9996

   False coordinates of origin = 500000 m Easting

   Nil m Northing

   Datum = WGS 1984

   Study area boundary

   latitude 0^0 15' 44.3" to 0^0 23' 20.2"

   longitude 34^0 02^0 32.7", to 34^0 11' 10.3"

   Hemisphere = North
4. Acquisition of ETM Landsat satellite images from the internet and the Regional Centre for Mapping of Resources for Development, Kasarani, Kenya. (Bands 1 – 5, 7)
5. Screen digitizing of the topographic map
6. Importing the satellite image into ILWIS and ERDAS in .TIF format
7. Creating a sub map of each imported satellite image

8. Analysing and processing the satellite images bands (lineaments) and exporting into ArcView 3.2 GIS
9. Create a map integrating land cover, lineament density, drainage density, elevation and slope, seismic profiles and geology into a groundwater potential map.

3.2 Landsat Imagery

This study is an attempt to correlate lineaments (or geologically linear features) visible on Enhanced Thematic Mapper (ETM) Landsat imagery, as a tool for hydrogeological exploration. The Landsat 7 satellite uses an instrument that collects seven images at once. Each image shows a specific section of the electromagnetic spectrum, called a band. Landsat 7 has seven different bands. Table 3.1 below shows the seven bands of Landsat 7.

Table 3.1: Spectral sensitivity of Landsat 7 Bands

Band Number	Wavelength Interval	Spectral Response
1	0.45-0.52 µm	Blue-Green
2	0.52-0.60 µm	Green
3	0.63-0.69 µm	Red
4	0.76-0.90 µm	Near IR
5	1.55-1.75 µm	Mid-IR
6	10.40-12.50 µm	Thermal IR
7	2.08-2.35 µm	Mid-IR

Landsat ETM satellite images Earth Sat Ortho, GeoCover images were downloaded from the internet from *www.landcover.org* . The images were acquired on 5th February 2001 during the dry period. Considering spatial resolution of the available satellite images and the size of the study area, Landsat ETM image is selected for this study. This image has a resolution of 30 m which can easily detect the lineaments. Lower resolution satellite image (e.g. 80 m and larger cell size) may not be suitable to detect the lineaments. Higher resolution images, on the other hand, may complicate the process and can detect minor lineaments not interested in (Sarp, 2005). The satellite images were from row 170 path 60 which covers an area of 185 km by 185 km, including Uganda. In selecting the satellite data for the study, Landsat ETM data were preferred, due to the availability of a large spectrum of bands, mainly in the near and medium infrared portion of the electromagnetic spectrum (em), the most suitable for lineaments and terrain analyses. Digital processing and GIS tasks were performed on a PC-based system using ArcView 3.2 GIS software, Ilwis 3.3Academic Open and Erdas Imagine 9.1 image analysis softwares.

Digital Remote Sensing and edge extraction techniques were applied in order to create proper thematic and lineament maps which were used as input data to the lineament identification scheme. For the study area the semantic framework for the construction of the knowledge-based lineament identification scheme was based on the satellite image. The satellite image was processed in order to provide adequate spectral information related to analysis of lineaments.

3.3 Lineaments

A lineament as a mappable, simple or composite linear feature of a surface whose parts are aligned in a rectilinear or slightly curvilinear relationship and which differ from the pattern of adjacent features and presumably reflects some sub-surface phenomenon. (Khairul, et al. 2000). Lineaments have been used in many applications: petroleum and mineral exploration, nuclear energy facility sitings, and water resource investigations. Generally lineaments are underlain by zones of localized weathering and increased permeability and porosity.

3.3.1 Manual lineament extraction

In manual extraction method, the lineaments are extracted from satellite image by using visual interpretation. The lineaments usually appear as straight lines or "edges" on the satellite images which in all cases contributed by the tonal differences within the surface material. Some general features, however, help to identify the lineaments can be listed as follows as already described in the literature:

- Topographic features such as straight valleys, continuous scarps,
- Straight rock boundaries,
- Systematic offset of rivers,
- Sudden tonal variations,
- Alignment of vegetation.

According to Sarp (2005) a continuous straight valley is the most helpful feature as a primary identification criterion in image processing for lineaments because a satellite image has no direct information on the topography of the area. There are several image enhancement techniques that can contribute to manual lineament extraction. In this study two of commonly known techniques will be used in the preparation of the final lineament map. These are filtering operations and the colour composites.

First, a map will be prepared for each method. Procedure and the details of these maps are given in the sections that follow. Then, a single map will be generated from these two maps in which the repeated lineaments will be deleted. The main reason for using several techniques is that one single method may not detect all the lineaments because of the variation in the nature of surface material in the area such as variations in the vegetation density, topographic texture and elevation.

3.3.2 Filtering operations

One of the characteristic features of the satellite images is a parameter called spatial frequency which is defined as the number of changes in brightness value per unit distance for any particular part of an image. If there are very few changes in brightness value over a given area in an image, this is referred to as a low-frequency area. Conversely, if the brightness values change dramatically over short distances, this is an area of high frequency detail (Jensen, 2000). Therefore, filtering operations are used to emphasize spatial frequency in the image. This frequency can be attributed to the presence of the lineaments in the area. In other words, the filtering operation will sharpen the boundary that exists between adjacent units.

The main disadvantage of the filtering method is that it cannot effectively extract lineaments in low-contrast areas where features extended parallel to the sun directions and in mountain shadows

A common filtering operation involves moving a window with a certain kernel size (e.g. 3*3, 5*5, 7*7 etc.) For each pixel in the output file (resultant image) a new digital number value is calculated under that window and replaced to the central pixel of the window The High Pass filter selectively enhances the small scale features of an image (high frequency spatial components) while maintaining the larger-scale features (low frequency components) that constitute most of the information in the image.

Directional filters (edge detection filters) are designed to enhance linear features such as roads, streams, faults, etc. The filters can be designed to enhance features which are oriented in specific directions. Commonly used edge detection filters are Gradient-Sobel, Gradient-Roberts, and Gradient-Prewitt. Examples of filtered images that applied in the study area are shown in Figure 3.2 below. Gradient-Sobel and Gradient-Prewit methods have been used in this research.

Directional Gradient-Sobel and Gradient-Prewitt filters are applied to the Landsat ETM band 4 in N-S, E-W, NE-SW and NW-SE directions to increase frequency and contrast in the image. The directional filters in four principal directions are given in table 3.2 below

Table 3.2: Sobel and Prewitt filters in four main directions applied in this study.

	N – S			NE - SW			E - W			NW - SE		
Sobel	-1	0	1	-2	-1	0	-1	-2	-1	0	1	2
	-2	0	2	-1	0	1	0	0	0	-1	0	1
	-1	0	1	0	1	2	1	2	1	-2	-1	0
Prewit	-1	0	1	-1	-1	0	-1	-1	-1	0	1	1
	-1	0	1	-1	0	1	0	0	0	-1	0	1
	-1	0	1	0	1	1	1	1	1	-1	-1	0

The results of the Gradient-Sobel and Gradient-Prewit filter operations are given in Figures 4.1 to 4.4 and figure 4.6 to 4.9, respectively, for four main directions. These figures belong to a small section in the study area to show the details of the results obtained.

All lineaments in Landsat band 4 image (directional filter) are traced separately. The tracings were overlapped and all the lineaments which are present in both tracings are traced again in the third tracing, until all the lineaments are plotted onto one map.

CHAPTER 4 : ANALYSIS OF DATA FROM MATAYOS – FUNYULA AREA

4.0 Analysis of data

4.1 Lineaments extraction from directional filters

Ilwis 3.3 Academic software, a user friendly and widely distributed GIS and image processing software, was used for processing and analysis of the satellite images to derive information on lineaments for the study area.

The satellite images of band 4 were imported as raster images. These were then enhanced using the directional filters as described in table 3.2. These filters are designed in a way that edges running in a particular direction (e.g. horizontal, vertical and diagonal) are enhanced. The output maps were then viewed in gray scale.

The results of the Gradient-Sobel filtering process are shown in figures 4.1 to 4.4.

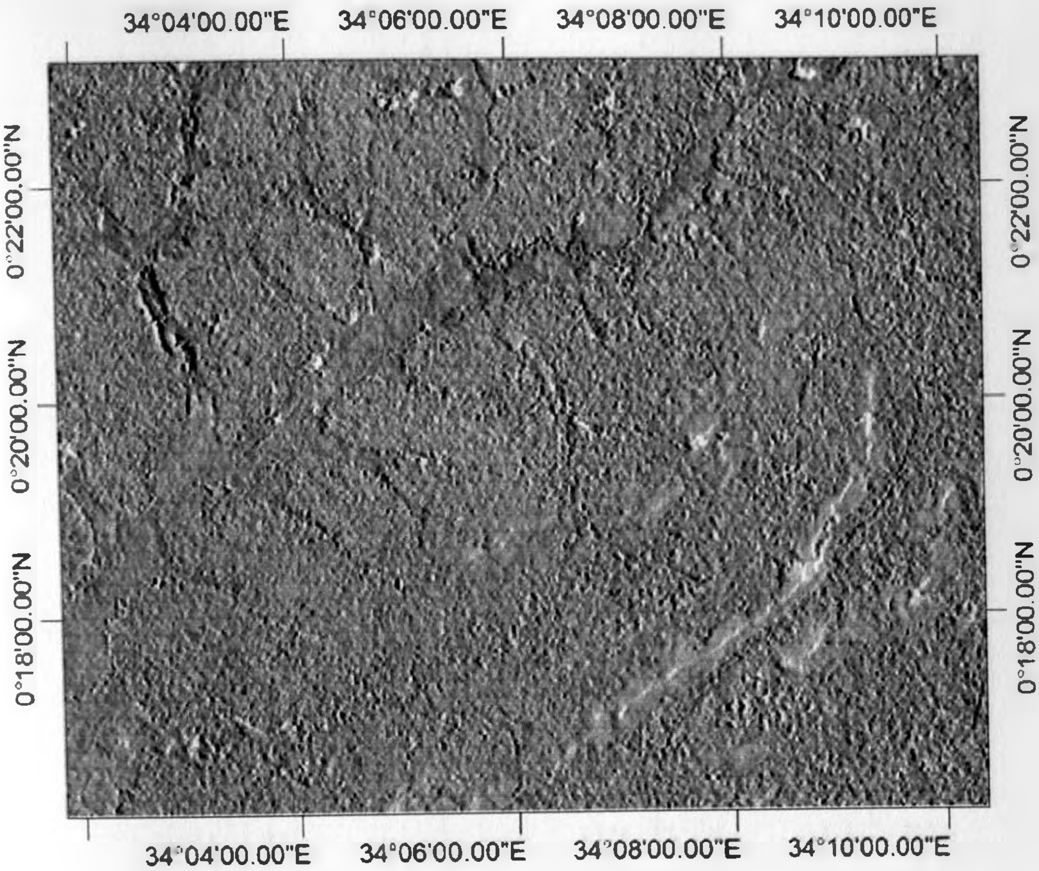


Figure 4.1: Sobel filtered image of the study area in N – S direction.

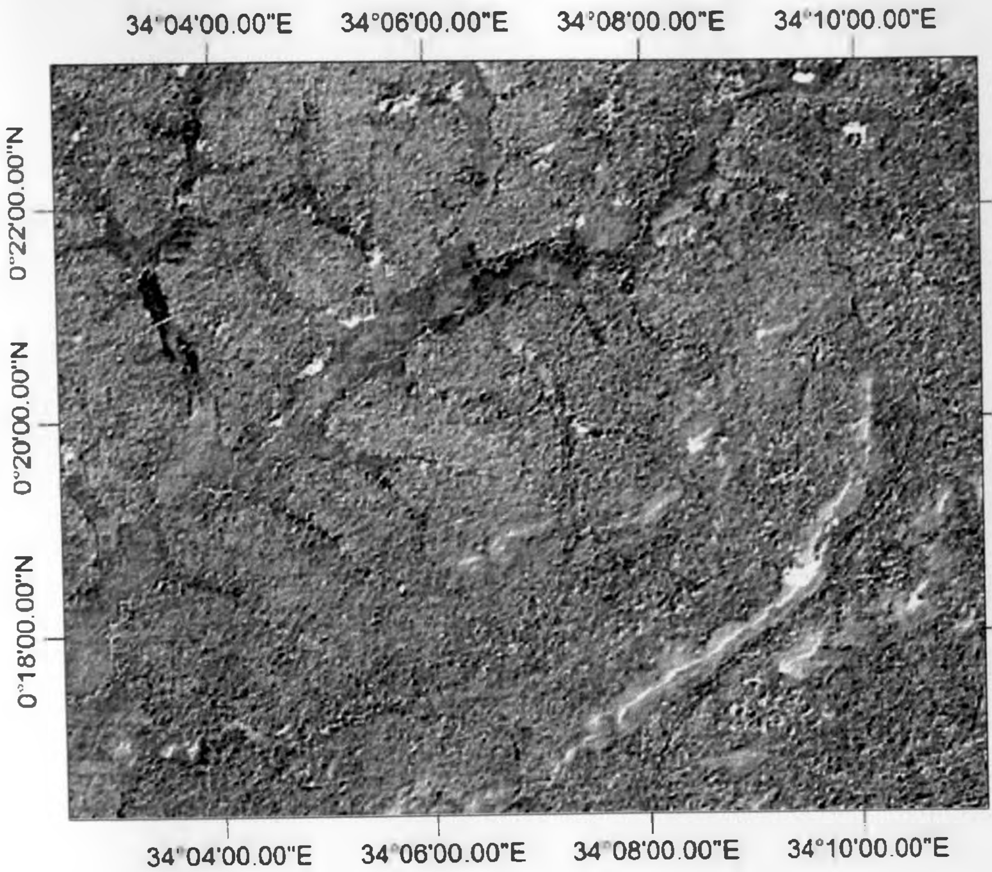


Figure 4.2: Sobel filtered image of the study area in NE – SW direction.

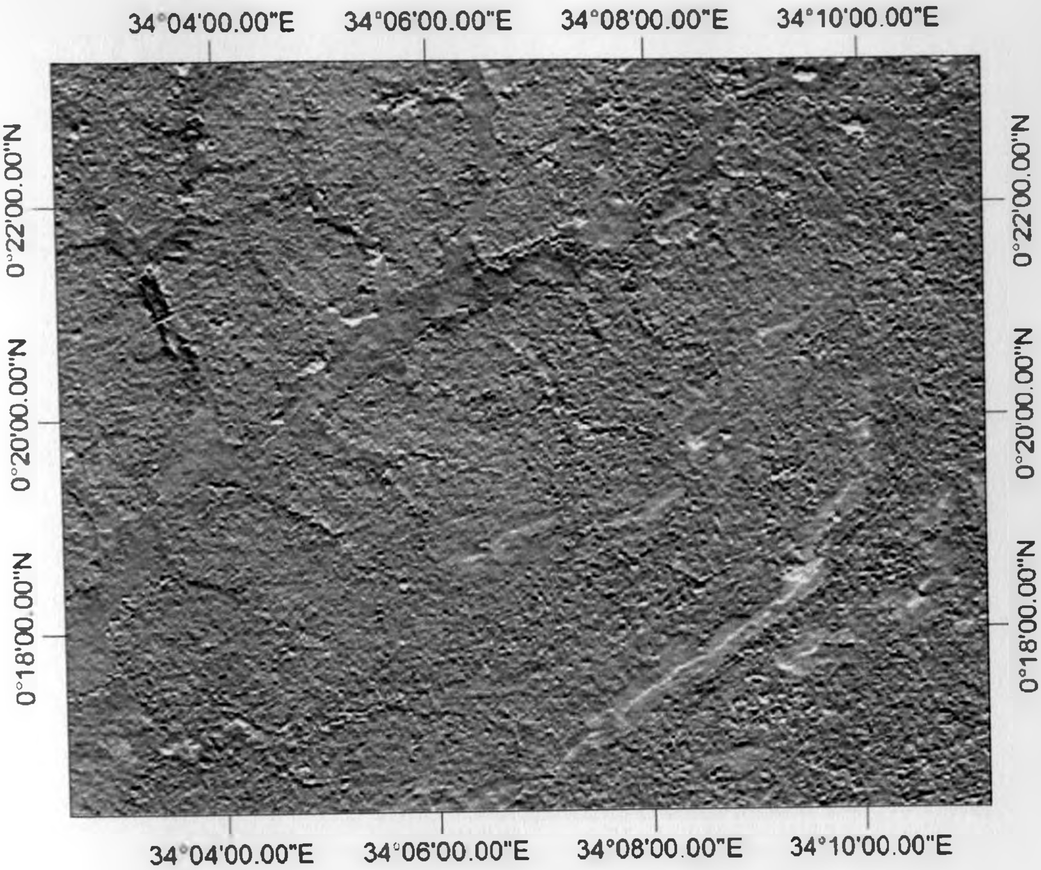


Figure 4.3: Sobel filtered image of the study area in E – W direction.

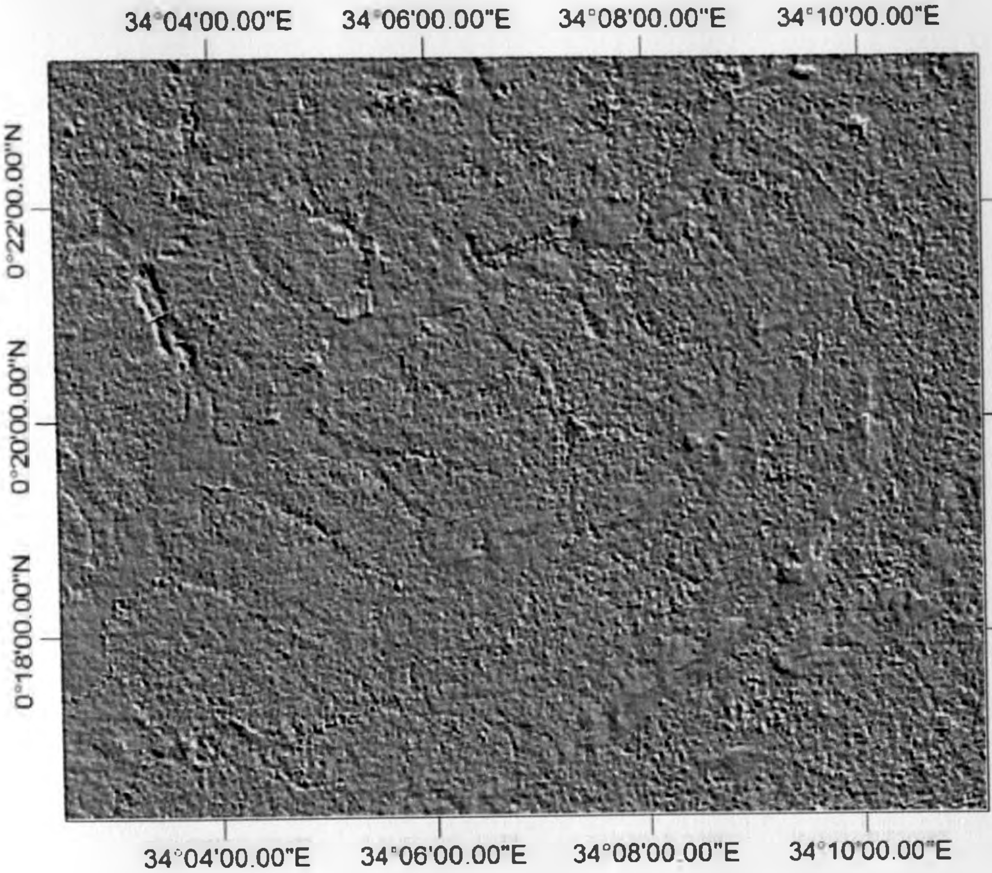


Figure 4.4:Sobel filtered image of the study area in NW – SE direction.

The results of the Gradient-Prewit filtering process are shown in figures 4.6 to 4.9.

Figure 4.5: Prewitt filtered image of the study area in N-S direction.

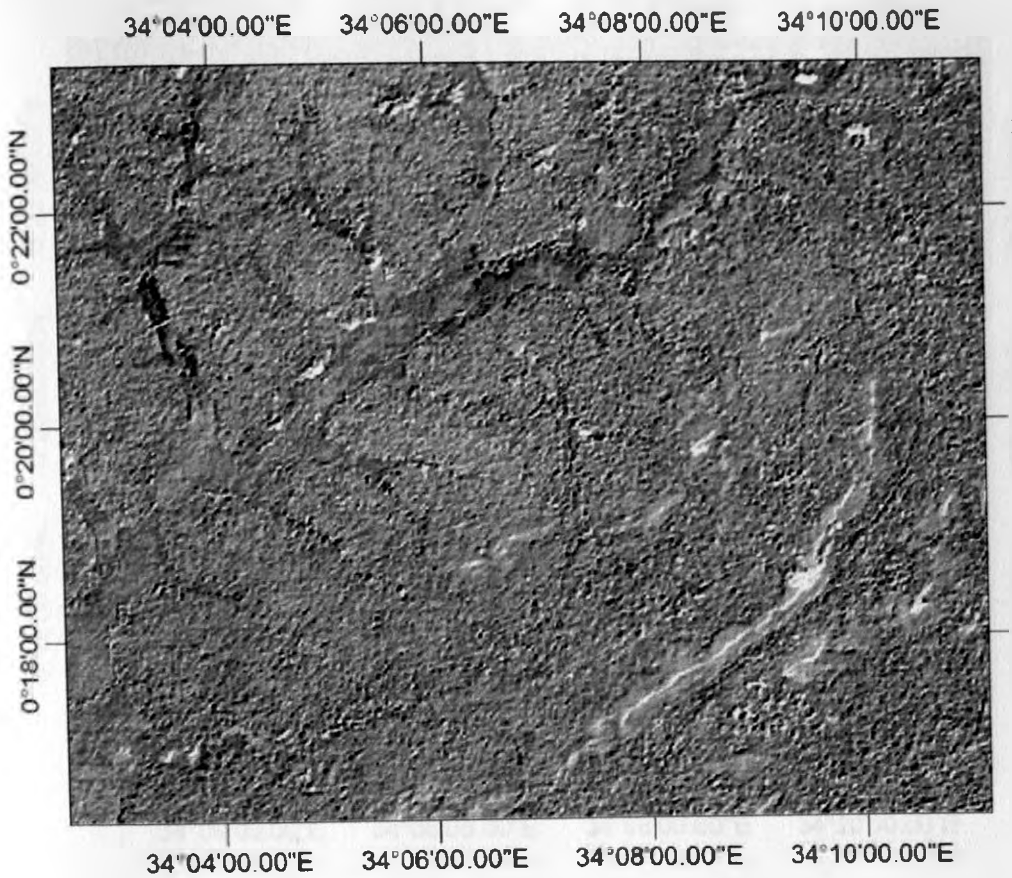


Figure 4.6: Prewitt filtered image of the study area in NE-SW direction.

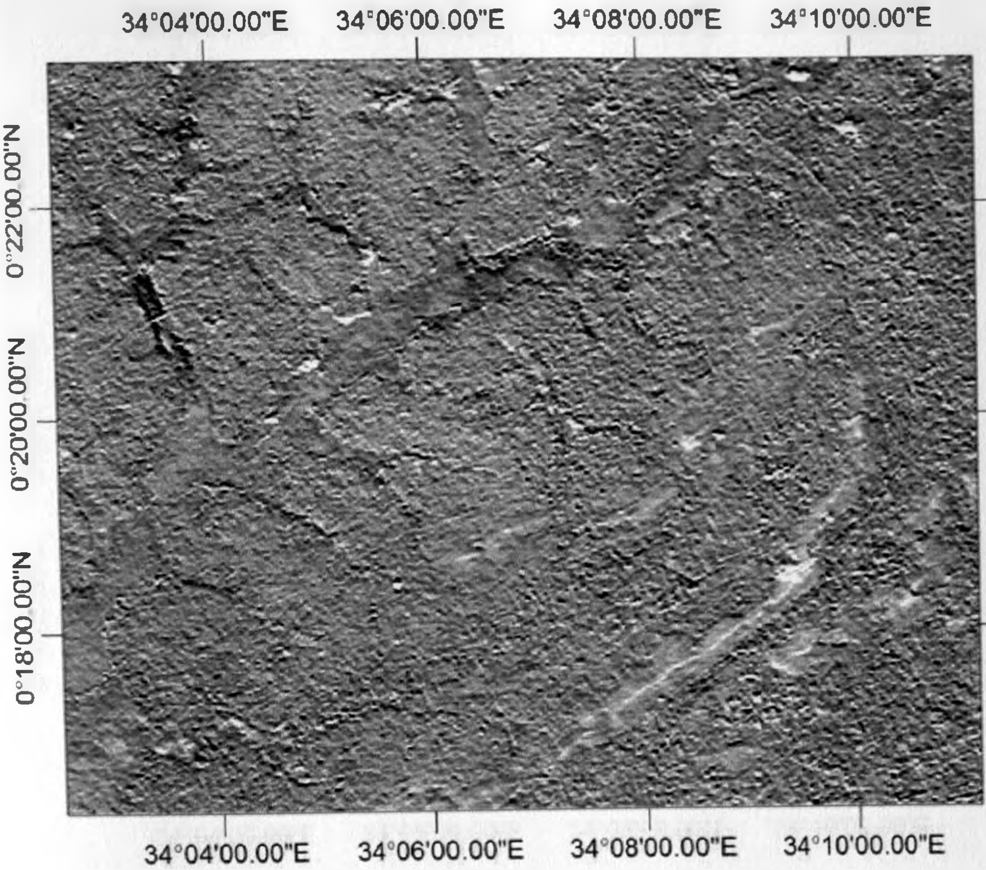


Figure 4.7: Prewitt filtered image in E – W direction.

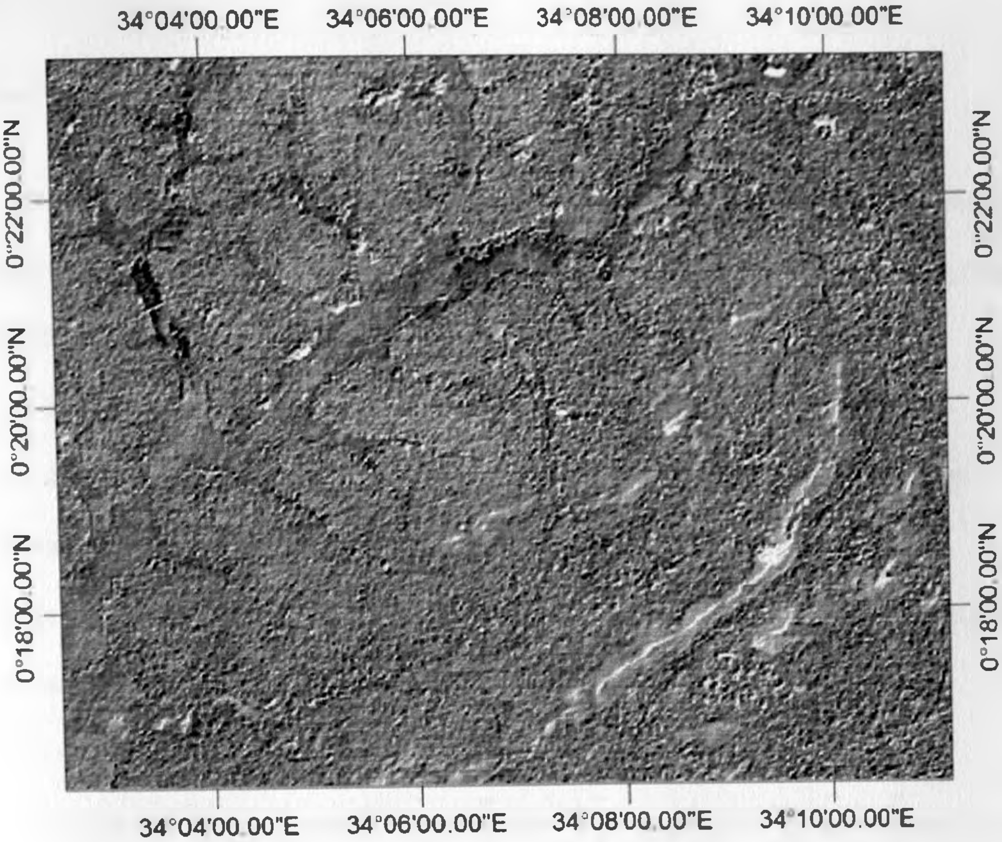


Figure 4.8: Prewitt filtered image of the study area in NW-SE direction.

4.2 Final lineament map

A new map was created with all common lineaments for Prewit and Sobel filtering operations. In this map the common lineaments were replaced by one instead of two. The following criteria were used in the process:

1. All lineaments from both sources are initially included.
2. Lineaments that are indicated on the eight sources and obviously indicate the same feature are replaced by one single lineament.
3. If the lineaments obviously coincide in the eight maps but still differ a little in azimuth or location the new lineament is placed between any two others.
4. The new lineament gets the same length as the longest of the original ones.

The idea with this operation is to merge as much information as possible in one map and to use this in the analysis.

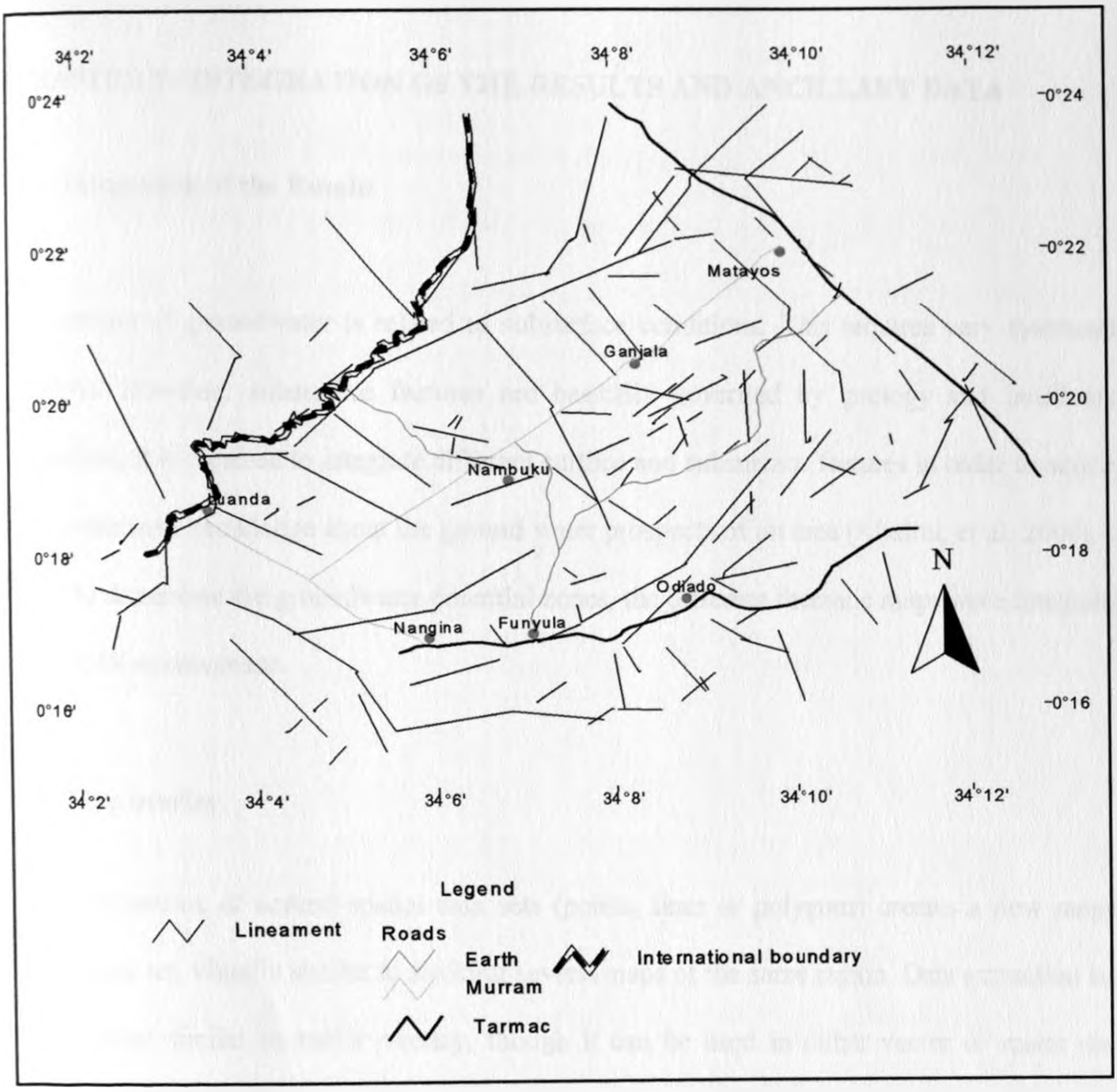


Figure 4.9: Combined lineament map of the study area derived by combining Sobel and Prewit lineament maps.

CHAPTER 5 : INTEGRATION OF THE RESULTS AND ANCILLARY DATA

5.0 Integration of the Results

Occurrence of groundwater is related to subsurface conditions. This requires very systematic analysis. However, subsurface features are basically governed by geology and landforms. Therefore, it is required to integrate different surface and subsurface features in order to acquire comprehensive knowledge about the ground water prospects of an area (Khairul, et al. 2000). In order to demarcate the groundwater potential zones, the different thematic maps were integrated in the GIS environment.

5.1 Map overlay

The combination of several spatial data sets (points, lines or polygons) creates a new output vector data set, visually similar to stacking several maps of the same region. Data extraction is a GIS process similar to vector overlay, though it can be used in either vector or raster data analysis. Rather than combining the properties and features of both data sets, data extraction involves using a "clip" or "mask" to extract the features of one data set that fall within the spatial extent of another data set.

In raster data analysis, the overlay of data sets is accomplished through a process known as "local operation on multiple rasters" or "map algebra," through a function that combines the values of each raster's matrix. This function may weigh some inputs more than others through use of an "index model" that reflects the influence of various factors upon a geologic phenomenon.

Each mapped factor is classified either into ranges (for continuous variables) or into significant media types (for thematic data) which have an impact on groundwater potential. The typical rating range is from 1 to 9. Weight factors are used for each parameter to balance and enhance their importance. The final vulnerability index (D_i) is a weighted sum of the six parameters and can be computed using the formula:

$$D_i = \sum_{j-1}^{6}(W_j \text{ X } R_j)$$

Where

D_i = Map Overlay Index for a mapping unit

W_j = Weight factor for parameter j

R_j = Rating for parameter j

Some of the factors do not affect the suitability of features of groundwater storage, yet have a positive or negative effect on the suitability for groundwater exploration. In a factor map, areas can be given different weights according to their suitability for groundwater exploration. For example one of the most important criteria that should be considered in groundwater exploration is the density of the fractures in the area. Therefore in fracture density map the values are decreasing with decreasing density. For each of these parameters a factor map was created.

On the other hand, the effects of these factors aren't the same in groundwater exploration. In this study, factor weights are defined to describe the significance of each parameter in the selection of location of the most favourable sites for groundwater exploration.

5.2 Weighted Index Overlay Model for Groundwater Prospects

Weighted overlay analysis is a simple and straightforward method for a combined analysis of multi-class maps. The efficacy of this method lies in that human judgement can be incorporated in the analysis. A weight represents the relative importance of a parameter vis-a-vis the objective. Weighted index overlay method takes into consideration the relative importance of the parameters and the classes belonging to each parameter. There is no standard scale for a simple weighted overlay method. For this purpose, criteria for the analysis should be defined and each parameter should be assigned importance (Saraf and Sarma, undated).

Determination of weightage of each class is the most crucial in integrated analysis, as the output is largely dependent on the assignment of appropriate weightage. Consideration of relative importance leads to a better representation of the actual ground situation (Saraf and Sarma, undated). Considering the hydro-geomorphic conditions of the area weighted indexing has been adopted to delineate groundwater prospective zones considering six parameters namely seismic profiles geology, geomorphology, soils, slope elevation, and lineaments.

A thematic map of each input factor was produced, derived from various sources including paper maps of topography, geology and hydrogeology, satellite images, water well records, and geophysical survey data. The input layers were ranked according to their relative importance in controlling groundwater potential. Each factor was divided into classes based on hydro-geological properties. The classes were then weighted according to their relative importance in controlling groundwater potential.

The final analyses were carried out under GIS environment by integrating all thematic maps by Index Overlay Method. The different ranks and weightages were given for each thematic layer and their parameters, respectively. The Index Overlay Method is one of the best methods of intergrading geological data to demarcate the potential groundwater prospecting zones.

In order to produce a map, a GIS model has been used to integrate thematic maps such as aquifer thickness, lithology (geology), lineament density, land use, slope steepness and drainage density. All the thematic layers were combined using the method that is modified from Sener, et al (2005), which has also been used to assess groundwater pollution vulnerability in Mombasa (Munga, et al, 2004). The formula used for groundwater potential is

$$GWP = Sp + Lt + Ld + Lu + Ss + Dd$$

where:

Sp= Seismic profiles, Lt = Lithology, Ld = Lineament Density, Lu = Land Use, Ss = Slope steepness, Dd=Drainage density

Each thematic layer consists of a number of polygons, which correspond to different features. The polygons in each of the thematic layers have been categorised, depending on the suitability/ relevance to groundwater potential, and suitable weights were assigned. The highest assigned is 9 and the lowest 1.

The overly process combined features of several layers to create a new layer that contains the attributes of all. This layer can be analysed to determine which features overlap, or to find out how much of a feature is in one or more areas. The groundwater potential map was constructed using ModelBuilder in Arcview 3.2 GIS software. The layers were converted into a single datum to allow for seamless analysis, processing and overlaying of the thematic layers.

Table 5.1: Factor weights

Factor	Percentage contribution
Lineament	22
Aquifer thickness	19
Slope steepness	18
Drainage	14
Geology	14
Land use	11
Total	100

The percentage influence determines the relative importance, or weight, of the factor to the model. Finally, a model was run to create an overall groundwater potential map.

5.3 Thematic layers

5.3.1 Lineament analysis

Lineaments are structural lines such as faults, which often represent zones of fracturing and increased secondary porosity and permeability, and therefore of enhanced groundwater occurrence and movement.

Lineaments give a clue to movement and storage of groundwater (Sener, et al, 2005) and therefore are important guides for groundwater exploration. A lineament density map was prepared by using length (in km) per km^2 (Figure 4.15). Suitable weightages for lineament density are shown in table 5.4 below.

Table 5.2: Lineaments weights

Lineament density (Km./sq. km)	Weight
0 – 0.851	1
0.851 – 1.323	3
1.323 – 1.795	6
1.795 – 2.268	8

Groundwater potential map from the analysis of the lineaments is shown in figure 5.1 below

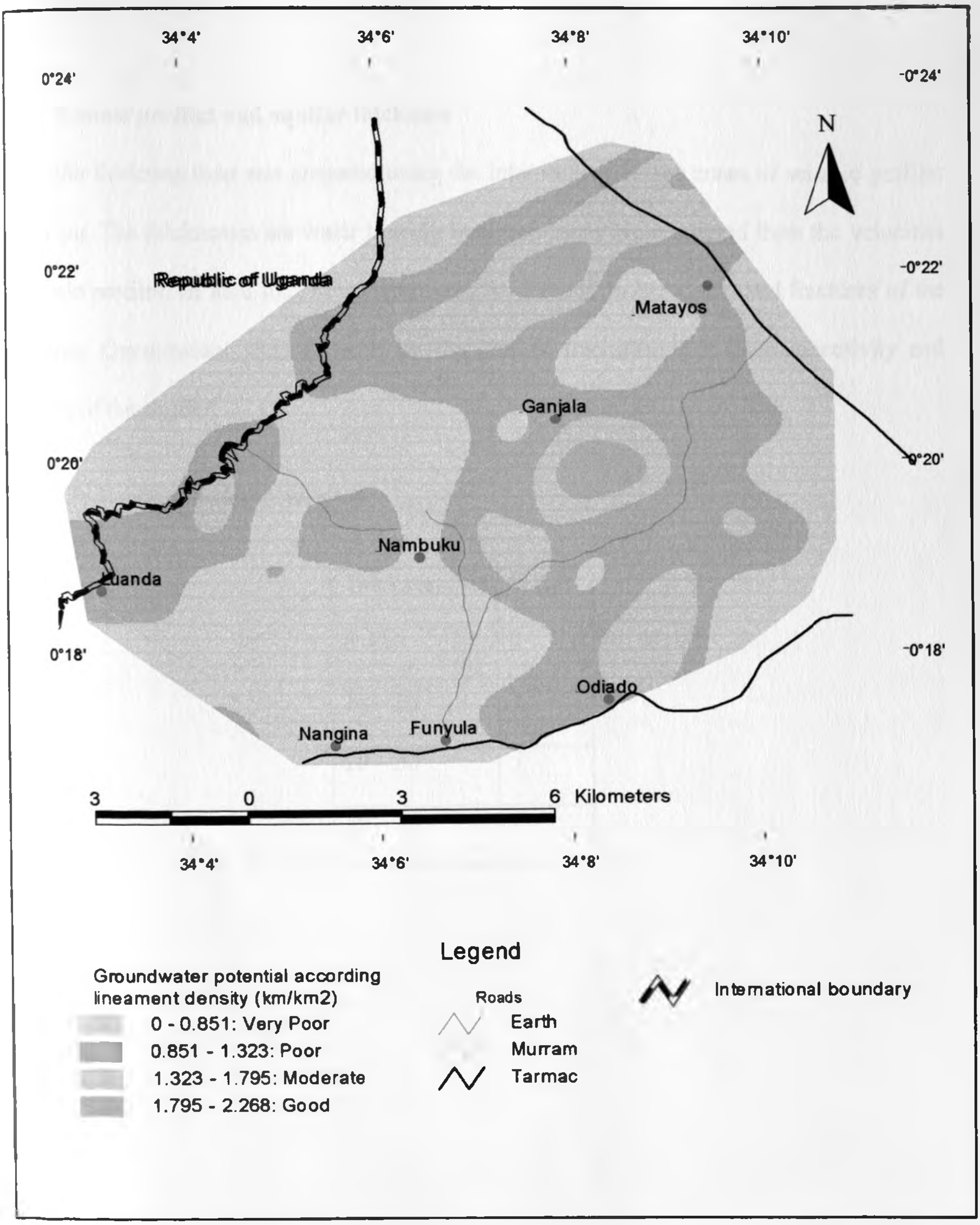


Figure 5.1: Groundwater potential of the study area in relation to lineament density

5.3.2 Seismic profiles and aquifer thickness

An aquifer thickness map was prepared using the interpreted fracture zones of seismic profiles carried out. The thicknesses are water bearing fractured zones were inferred from the velocities of seismic profiles. In hard rock areas, groundwater is found in the cracks and fractures of the local area. Groundwater yield depends on the size of fractures, their interconnectivity and thickness of the aquifer.

Table 5.3: Aquifer thickness weights

Thickness (m)	Weight
0 – 10	2
10 – 20	3
20 – 30	5
30 – 50	7

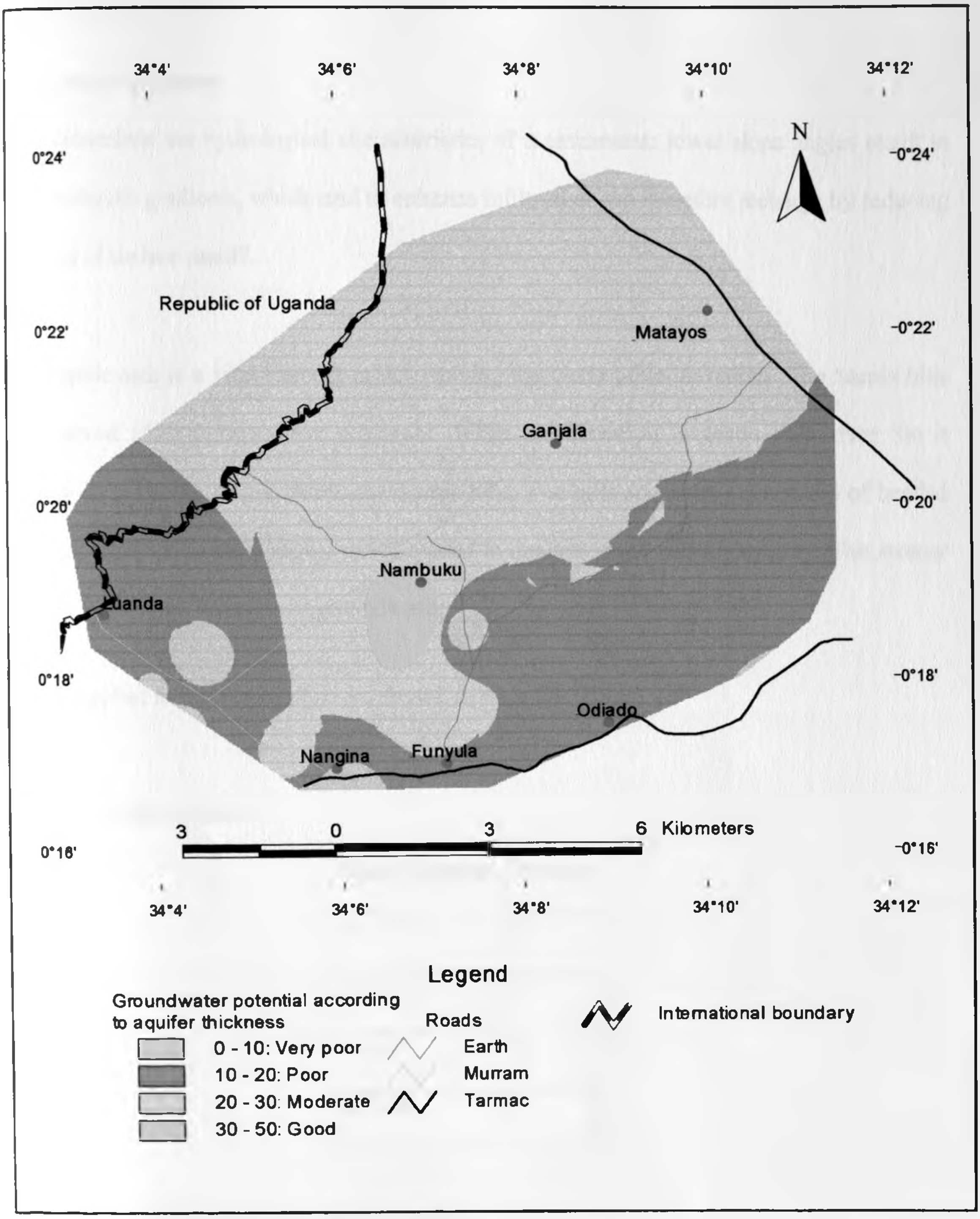


Figure 5.2: Groundwater potential in relation to aquifer thickness

5.3.3 Slope steepness

Slope determines the hydrological characteristics of a catchment: lower slope angles result in lower hydraulic gradients, which tend to enhance infiltration and therefore recharge by reducing the speed of surface runoff.

Topographic data is a vital element in determining the water table elevations. The Samia hills rise to about 1560 metres above sea level. While the elevation is gentle from river Sio it suddenly rises steeply as one climbs the Samia hills. The hills are mainly composed of banded quartzites. Table 5.4 below shows weights used to analyse slope and topography. The steeper the slope the less the retention of groundwater.

Weights applied in relation to slope are shown in table 5.4.

Table 5.4: Slope weights

Slope (degrees)	Weight
0 – 5	8
5 - 15	5
15 - 45	2
45 - 90	1

The resultant map is as shown in figure 5.3 below

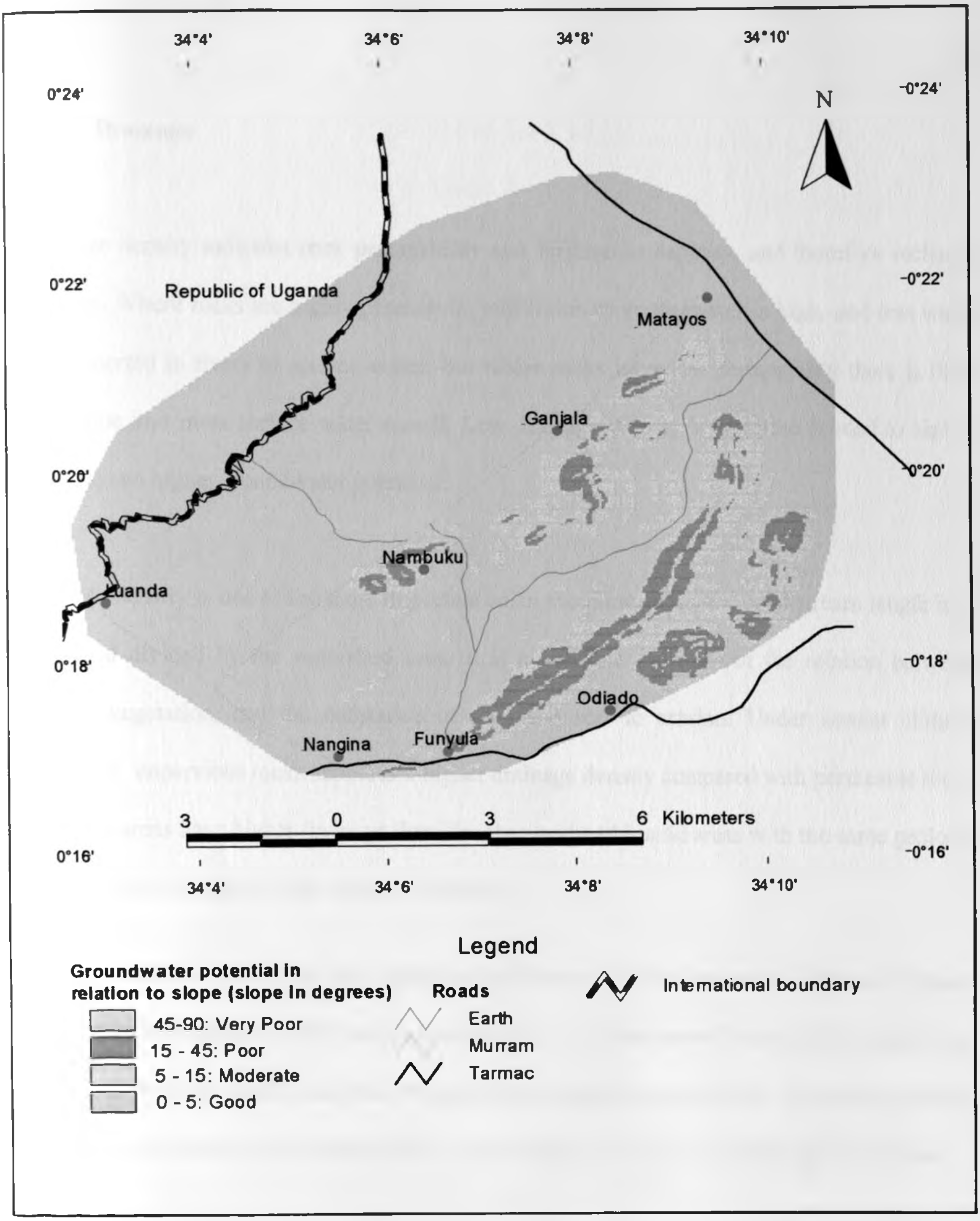


Figure 5.3: Groundwater potential map in relation to slope

5.3.4 Drainage

Drainage density indicates rock permeability and infiltration capacity, and therefore recharge capacity. Where rocks are highly permeable, infiltration to groundwater is high, and less water is transported in rivers as surface water; but where rocks have low permeability there is little infiltration and more surface water runoff. Low drainage density is therefore related to higher recharge and higher groundwater potential.

Drainage density is one of the most important basin morphometrics, the total stream length in a watershed divided by the watershed area. It is a valuable indicator of the relation between climate, vegetation, and the resistance of rock and soil to erosion. Under similar climate conditions, impervious rocks supports a higher drainage density compared with permeable rock. Semi-arid areas have higher drainage densities than arid and humid areas with the same geology because of the rapid runoff and sparse vegetation.

Drainage pattern is one of the most important indicators of hydro geological features, because drainage pattern, texture and density are controlled in a fundamental way by the underlying geology. A drainage density map was prepared from length (in km) per km^2. In addition a table of suitable weightages for drainage density was also prepared and presented in table 5.5 below

Table 5.5: Drainage weights

Drainage density (No./sq. km)	Weight
0 – 0.5	1
0.5 – 1	3
1 – 1.5	5
1.5 – 2.0	6

The groundwater potential map derived from the above weights is as shown in figure 5.3.

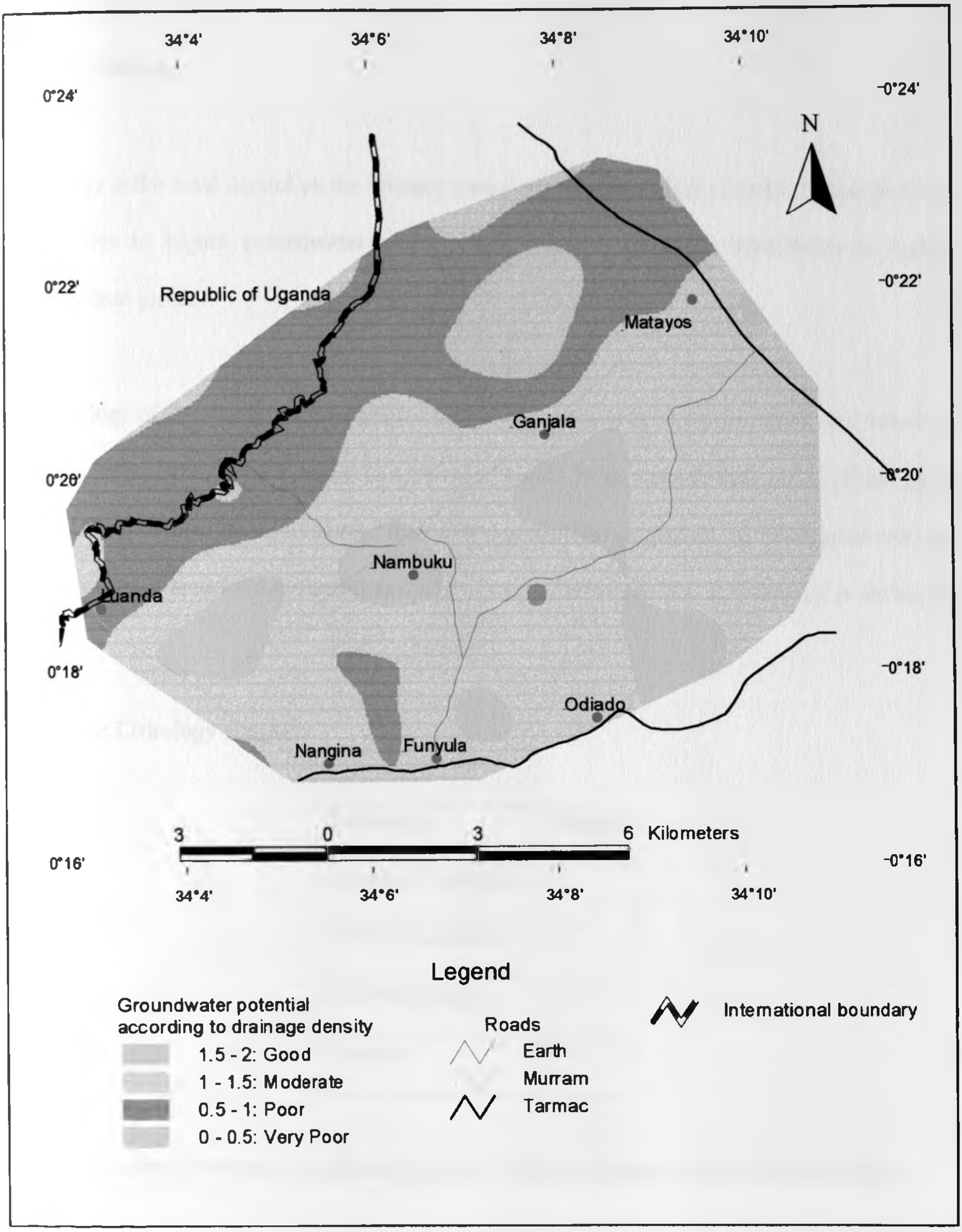


Figure 5.4: Groundwater potential map of the study area in relation to drainage density

5.3.5 Lithology

Lithology is the main control on the primary porosity and permeability of rocks. Higher porosity contributes to higher groundwater storage, and higher permeability contributes to higher groundwater yields.

The geology of the area is mainly composed of Nyanzian volcanics, banded quartzites, laterites, and recent alluvium on the banks of river Sio. Yields from wells drilled in the general area range from 0 to 14m^3/h. According to their hydro geological properties, the lithological units in the investigated area were evaluated and a list of suitable weightages for lithology is shown in Table 5.3

Table 5.6: Lithology weights

Lithology	**Weight**
Nyanzian Andesites	5
Banded quartzites	3
Alluvial deposits	7
Laterites	4

Figure 5.5 below shows the groundwater potential of the area analysed in relation to lithology.

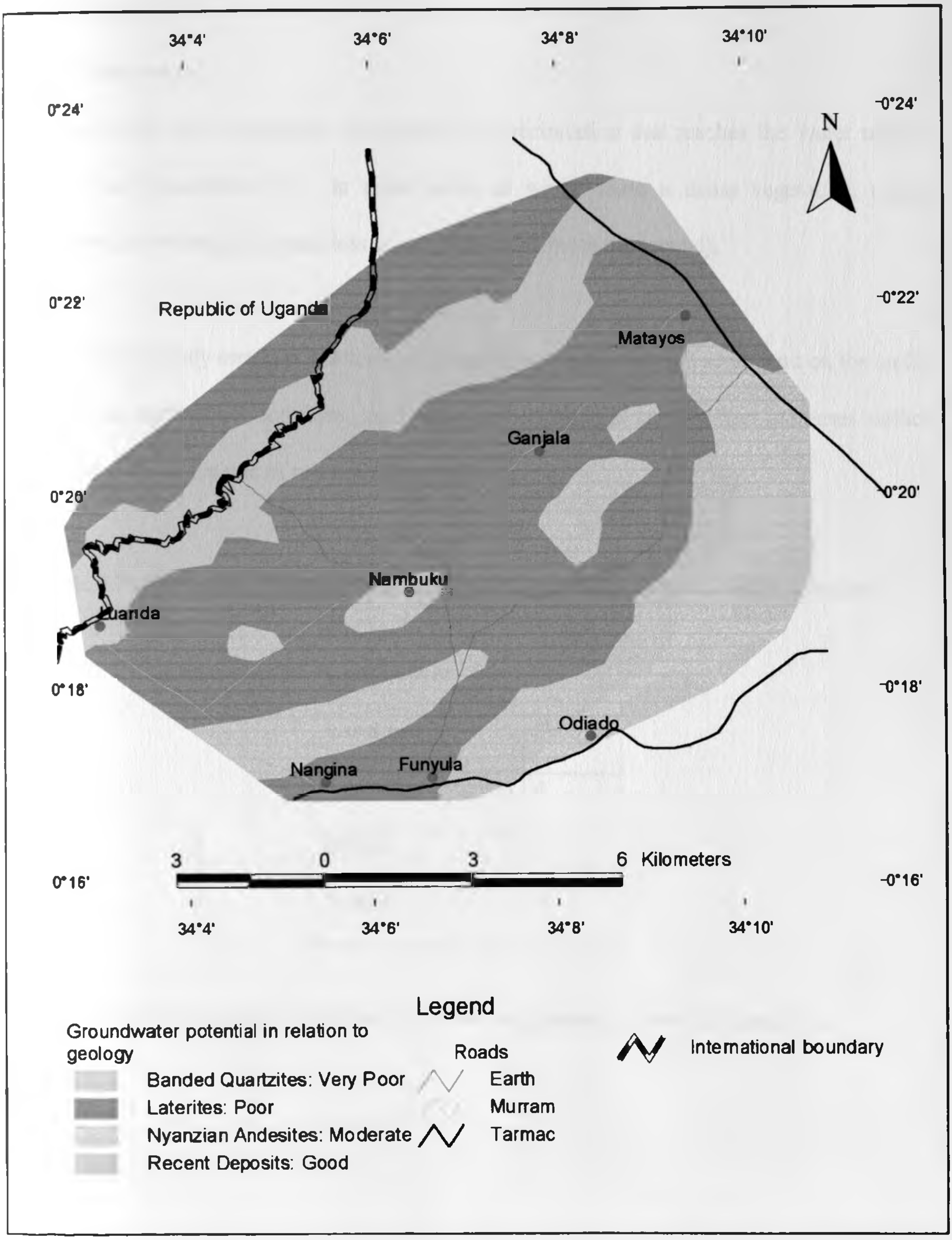


Figure 5.5: Groundwater potential of the study area in relation to lithology

5.3.6 Land cover

Land use/ land cover determines the amount of precipitation that reaches the water table to recharge the groundwater (e.g. in urban areas or where there is dense vegetation, rain is intercepted above the ground and less is available to infiltrate the ground).

Land use in the study area is characterised by agricultural activities and scrub land on top on the hills. Due to agricultural activities, land cover is reduced and this in effect increases surface runoff and reduces the rate of recharge of groundwater.

The table 5.7 below shows the weights applied to land use to assess groundwater potential

Table 5.7: Weightages applied to land cover

Land use	**Weight**
Agriculture (dense)	4
Marsh	6
Shrubs	5

The groundwater potential derived from the above weightages is shown in figure 5.6 .

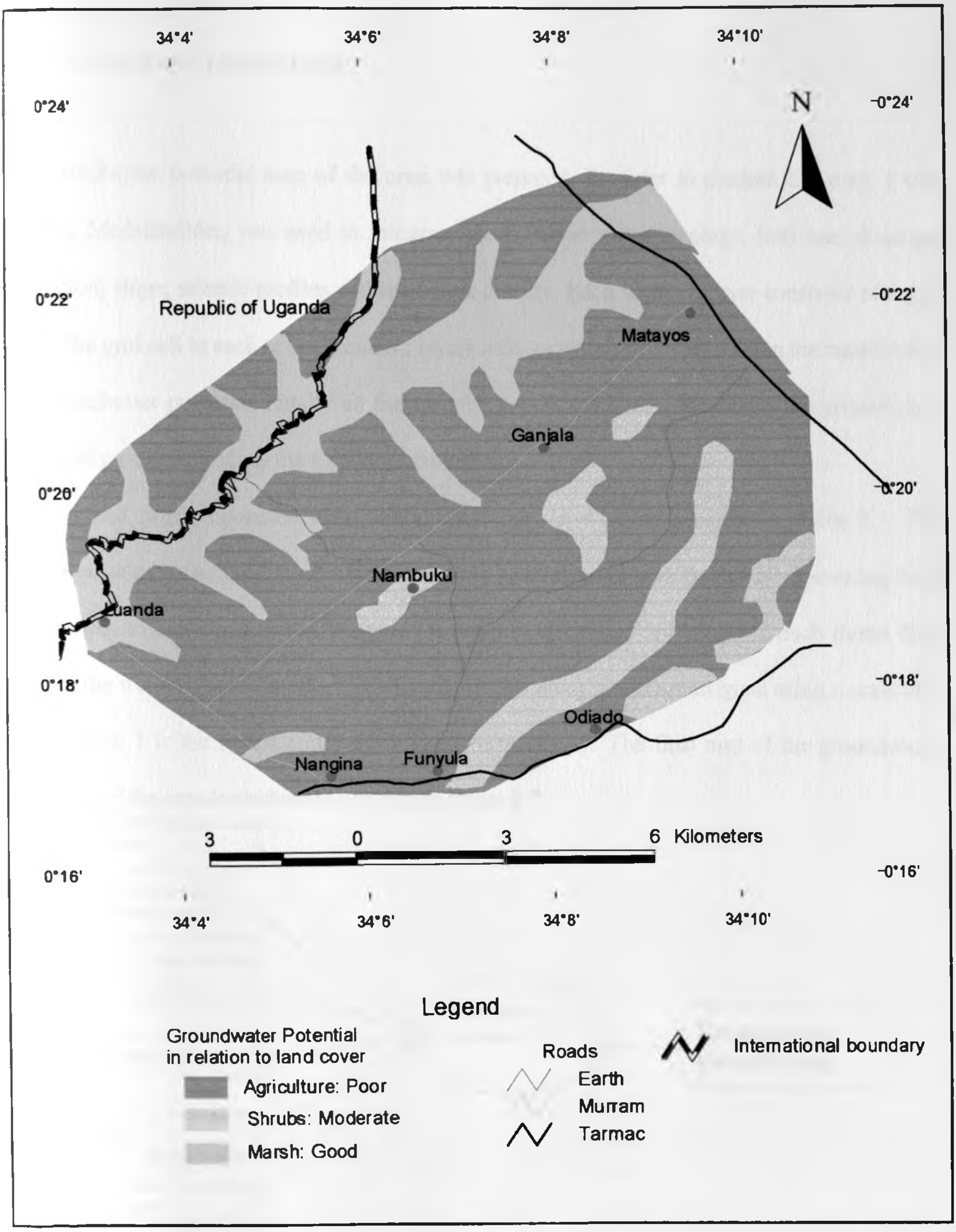


Figure 5.6: Groundwater potential in relation to land use

5.4 Groundwater potential map

A groundwater potential map of the area was prepared. In order to produce the map, a GIS model, ModelBuilder, was used to integrate the thematic maps: geology, land use, drainage, elevation, slope, seismic profiles and lineament density. Each thematic layer consisted of a grid cell. The grid cell in each of the thematic layers were categorised, depending on the contribution to groundwater potential. Finally all the thematic layers were integrated using the groundwater potential model to produce the final derived layers.

A weighted overly operation was carried out using the weights indicated in Table 5.1. The weighted overly was used to combine data from several input grid themes by converting their cell values to a common scale, assigning a weight (percentage influence) to each theme then adding the weighted cells together. The assigned percentages were reassigned using a scale of 1 to 9, where 1 is the lowest and 9 the highest, respectively. The final map of the groundwater potential of the area is produced as shown in figure 5.7.

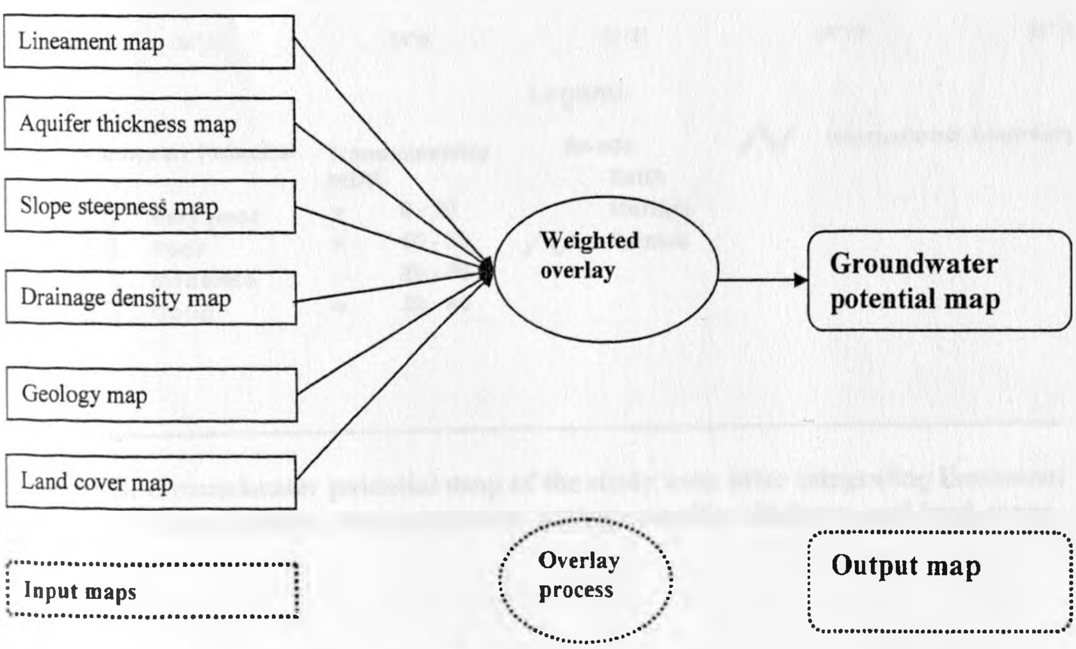


Figure 5.7: Schematic diagram showing the process employed.

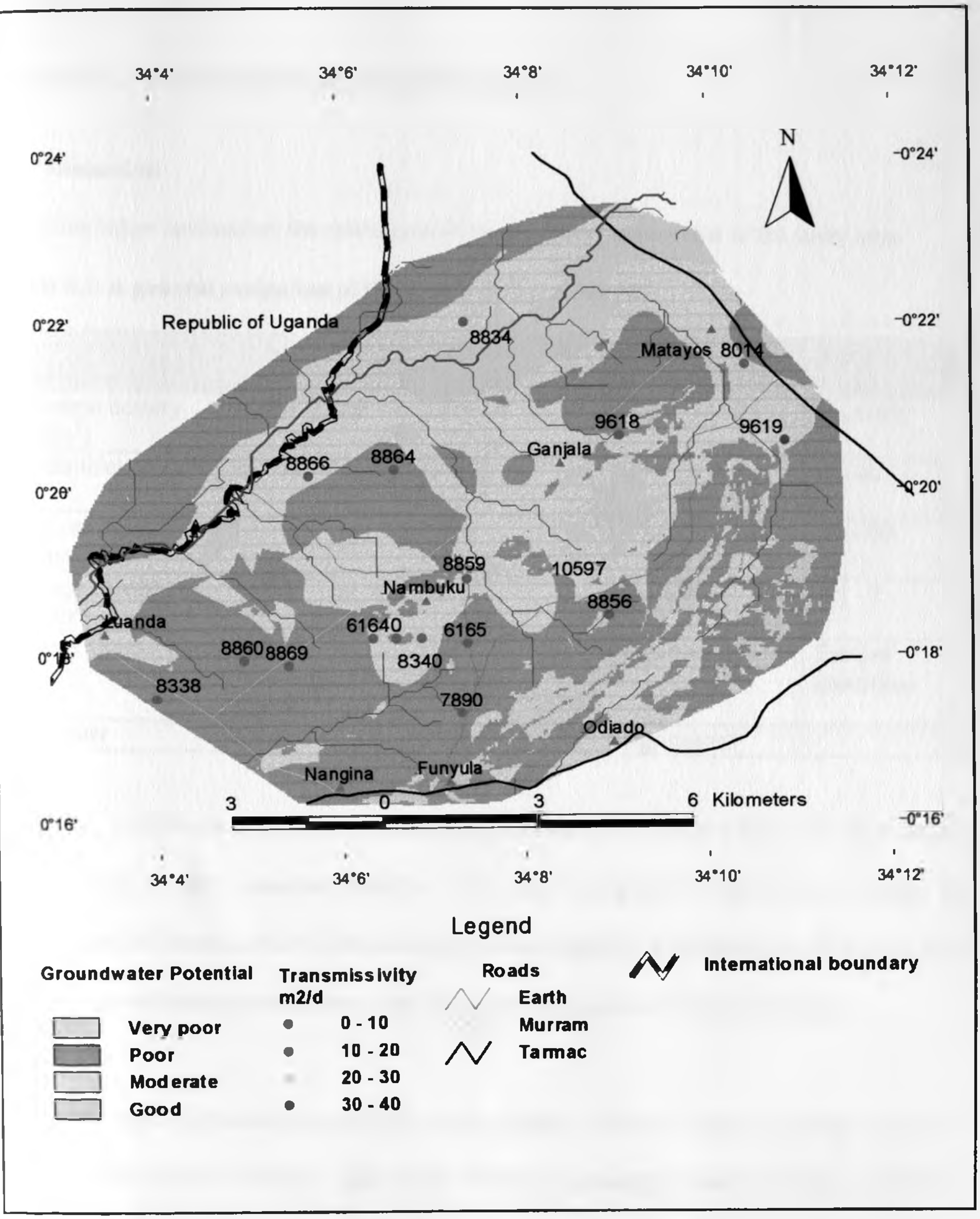


Figure 5.8: Groundwater potential map of the study area after integrating lineament density, drainage density, slope steepness, geology, aquifer thickness and land cover.

CHAPTER 6 : DISCUSSION AND CONCLUSION

6.0 Discussion

The table below summarises the evaluation of the groundwater potential of the study area.

Table 6.1: A general evaluation of the groundwater potential

Groundwater potential zone	Good	Moderate	Poor	Very poor
Lineament density (km/km^2)	1.795 – 2.268	1.323 – 1.795	0.851 – 1.323	0 – 0.851
Aquifer thickness (m)	30 – 50	20 – 30	10 – 20	0 – 10
Slope steepness (degrees)	0 – 5	5 – 15	15 – 45	45 – 90
Drainage density (km/km^2)	0 – 0.5	0.5 – 1	1 – 1.5	1.5 - 2
Geology (Rock type)	Recent (Alluvial) deposits	Nyanzian andesites	Laterites	Banded quartzites
Land cover	Marsh	Shrubs	Agriculture	-

According to Table 6.1, the areas having good groundwater potential are areas with recent deposits and a high lineament density. Low slope steepness increases the changes of groundwater infiltration, which in turn increases the potential for groundwater. The areas with very poor groundwater potential have high slope steepness and low lineament density

In order to predict groundwater potential zones, different thematic maps have been prepared. These include aquifer thickness, land cover, lithology (geology), lineament density, drainage density, and slope steepness. The final map showed the areas with the highest potential for groundwater exploration. Existing boreholes were plotted on the final map and they showed a fairly good correlation between the identified potential areas and boreholes transimissivities.

Satellite data has proven to be very useful and informative for sub-surface study, as it gives preliminary information and good background information on features such as lineaments and drainage density for further interpolation on the groundwater potential of a study area.

Groundwater exploration success can be greatly enhanced through the use of remote sensing to delineate structures that hold and transmit water like fractures and faults. Areas that had been thought to be dry or had tendency to yield dry boreholes in the study area can now be narrowed down to specific areas for detailed ground investigations.

The groundwater potential of the area is seen to be controlled by the structures that define the study area. For example, streams joining river Sio are straight and parallel, and oriented to the north west, showing that they follow point of structural weaknesses which can be interpreted to be fracture zones.

6.1 Conclusions & Recommendations

The object of this study is to demonstrate the information interpreted from remotely sensed imagery combined with conventional field and other data can improve the exploration process in terms of cost, accuracy and time. The present study has demonstrated this by compiling, registering, and analysing data obtained from various methods (Remote Sensing, Geophysics etc) in GIS for Matayos – Funyula. The ability to compare various data sets, individually or in combination, enables the exploration geologist to extract the maximum information possible and apply it to the groundwater exploration problem

Satellite data play a vital role in identifying structures in the study area as structure is easily readable from Satellite Image. Therefore, lineament analysis of remote sensing data together with conventional geological and geophysical investigations enables obtaining new additional information about groundwater bearing structures

Groundwater potential investigation in the Matayos-Funyula area can be greatly enhanced by incorporating remote sensing techniques .The most promising areas to carry out a groundwater investigation has been found to be between the Samia hills, as that area has the highest lineament and drainage density.

Integrated assessment of thematic maps using a model developed based on GIS techniques was a suitable method for predicting groundwater potential. In the research area, the areas of Matayos, Nambuku and Ganjala are important from the point of view of groundwater investigation according to this investigation.

From the above prepared map (figure 5.8), good groundwater potential areas have been identified. Therefore other ground methods can be applied to specific areas to investigate in detail for water supplies for the Nambuku, Matayos and Ganjala villages.

Appendix 1

NO	SEISMIC _LINE	OVERB URDEN	VELOCITY _WATER	VELOCITY_ BEDROCK	FRACT_ ZONE	THICK_ DRY_LAY ER	THICK_ WATER _LAYER	COOR D_N	COORD_ E	ALT_MA SL	HOLE_NO
626	BS-713	400	1530	4000	2900	3.4	12.0	42100	633100	1190	C-5189
657	BS-744	1400	1770	-1	-1	1.4	-1.0	30650	622500	1220	C-5967
658	BS-745	600	-1	4000	4000	-1.0	-1.0	30000	619200	1180	C-5453
713	BS-7100	400	2250	3770	3200	6.3	15.0	30000	624900	1230	C-5459
744	BS-7131	350	1550	4480	4480	15.0	24.0	32100	619250	1160	C-5969
745	BS-7132	440	-1	6500	3600	-1.0	-1.0	33400	619550	1170	-1
746	BS-7133	550	1300	3730	3730	1.8	28.0	31400	621300	1180	C-5968
747	BS-7134	620	1840	3300	3300	6.5	17.0	30850	619450	1160	C-5970
750	BS-7137	430	-1	5600	3000	-1.0	-1.0	29450	618500	1190	-1
801	BS-7188	350	1690	5210	4050	6.3	14.0	30200	626800	1220	C-6166
803	BS-7190	550	-1	4880	2900	24.0	-1.0	34000	624700	1220	C-6165
804	BS-7191	430	1710	5810	3700	6.9	24.0	31250	617400	1150	C-6114
806	BS-7193	440	1500	6000	6000	14.0	21.0	33500	622500	1205	-1
807	BS-7194	620	1460	5900	2600	1.8	35.0	33700	623300	1200	C-6164
817	BS-7204	-1	-1	-1	-1	-1.0	-1.0	30200	626800	1220	-1
868	BS-7255	475	1270	5000	4600	12.0	15.0	30850	624650	1250	-1
917	BS-7304	535	1560	6800	2850	3.4	30.0	32150	624200	1230	C-7890
918	BS-7305	875	1525	5000	3800	3.0	50.0	34200	623850	1240	C-8340
921	BS-7308	440	1750	5030	4300	12.0	13.0	30350	625500	1240	C-7892
922	BS-7309	310	1460	5840	4000	2.0	7.2	30850	627400	1280	-1
955	BS-7342	510	1690	5400	3300	12.0	22.0	32900	618750	1170	C-8338
968	BS-7355	500	1480	4120	2000	18.0	24.0	29650	618400	1180	C-8334
993	BS-7380	-1	-1	-1	-1	-1.0	-1.0	30300	621750	1220	-1
1020	BS-7407	500	1580	5500	3800	11.0	9.4	33750	633100	1300	C-8002
1021	BS-7408	1040	1700	3820	3820	17.0	29.0	40300	629700	1200	C-8014
1025	SI-703	380	1360	4800	3800	5.2	8.5	30180	629950	1250	-1
1069	SI-747	540	1500	4300	4300	21.0	35.0	29750	628000	1280	C-5457
1070	SI-748	385	1660	4500	4500	16.0	34.0	30450	628950	1270	C-5456
1184	SI-7162	400	1160	5940	4150	14.0	-1.0	29150	632900	1250	-1
1185	SI-7163	480	1430	5650	5500	-1.0	-1.0	31750	630650	1280	-1
1197	SI-7175	770	1625	5420	2750	20.0	19.0	29600	628500	1265	C-7977
1217	SI-7195	340	1830	6400	6400	19.0	18.0	29800	629750	1250	-1

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